Coconut Genetic Resources

Pons Batugal, V. Ramanatha Rao and Jeffrey Oliver, *editors*

The International Plant Genetic Resources Institute (IPGRI) is an independent international scientific organization that seeks to improve the well-being of present and future generations of people by enhancing conservation and the deployment of agricultural biodiversity on farms and in forests. It is one of 15 Future Harvest Centres supported by the Consultative Group on International Agricultural Research (CGIAR), an association of public and private members who support efforts to mobilize cutting-edge science to reduce hunger and poverty, improve human nutrition and health, and protect the environment. IPGRI has its headquarters in Maccarese, near Rome, Italy, with offices in more than 20 other countries worldwide. The Institute operates through four programmes: Diversity for Livelihoods, Understanding and Managing Biodiversity, Global Partnerships, and Improving Livelihoods in Commodity-based Systems.

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Cover pictures (*clockwise from upper left corner*):
Dr Pons Batugal, COGENT Coordinator, admiring the PNG Brown Dwarf x Renell Island Tall hybrid produced by PNG's Stewart Research Station; Vietnamese mother and child proudly showing seedling of local coconut variety they raised for planting; Mr Tiara Mataora, Senior Research Officer, Ministry of Agriculture, Cook Islands, admiring the typhoon-resistant local coconut cultivar; top view of the International Coconut Genebank for Africa and the Indian Ocean hosted by Côte d'Ivoire; Mr Lolo Fili, Researcher of Tonga, showing prized local coconut variety with high husk content. Pictures courtesy of Dr Roland Bourdeix.

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Foreword

Coconut is an important crop for poor people, supporting their livelihoods and the sustainability of their environment. It is a source of materials for food, drink and shelter. As a fundamental element in the food system it provides essential nutrition to people in coconut-growing communities. It stabilizes farming systems, especially in fragile environments such as small island states, atolls, and in coastal zones. And coconut generates much needed income for small growers as well as employment and foreign currency earnings for their countries.

Despite the enormous potential of the crop, coconut farmers in the past mostly scraped a living well below the poverty line. They were marginalized. About 96% of the farmers, who collectively grow coconuts on 12 million hectares worldwide, are smallholders tending less than four hectares. Many do not own the land they work, lack the resources to invest in technologies that would improve production, and are considered non-bankable by the formal banking sector. Despite its importance in the economies of many poor countries, the farmers who grow coconut lack a voice to influence government policy or private sector practices.

To address these problems, the Consultative Group on International Agricultural Research (CGIAR) decided to include coconut in its research portfolio in 1991. Case studies had indicated that international research on coconut would generate high pay-offs for resource-poor coconut farmers. The International Board for Plant Genetic Resources (IBPGR), now the International Plant Genetic Resources Institute (IPGRI), organized the International Coconut Genetic Resources Network (COGENT) to implement this decision. COGENT started with 15 coconut-growing countries as members and subsequently expanded to 38 member countries.

The substantive results of the work of the COGENT and its partner institutions across the developing and the developed world, reported in this book, are testimony to the correctness of the CGIAR's vision and its implementation by IPGRI. The work has seen a tremendous advance in the scientific basis of coconut conservation and use. It has also generated substantial institutional and funding support from member countries. COGENT's project on 'Poverty reduction in coconut growing communities,' which makes use of coconut diversity to improve livelihoods in 54 poor coconut-growing communities in 15 countries worldwide, is also described in this book. It illustrates the impact that research on coconut genetic resources generates for poor coconut farmers. It also describes the coconut conservation strategy that provides the way forward for this important area of work.

At least in some communities, coconut farmers now have the resources they need – genetic, social, legal, political and financial – to make better use of coconut and hence improve life for themselves and their families. The task now is to improve matters for all coconut growers, worldwide.

It is hoped that bringing together in this book the results of all COGENT's work to date will serve as a benchmark for planning new initiatives to address the emerging challenges and opportunities that stem from the continuing erosion of coconut genetic resources, and the constant pressure on the research community to help resource-poor coconut farmers.

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Introduction

The coconut industry is at the crossroads. Coconut farmers are suffering due to decreasing farm productivity and income and unstable markets for copra, the traditional dried kernel product. This situation arisen in part by the competition from other vegetable oils and further aggravated by ageing and senile coconut palms, natural calamites such as drought, typhoons, incidence of pests and diseases, lack of resources to invest in innovations to improve yields and incomes and lack of availability of affordable high-yielding and adapted coconut varieties. Important coconut diversity, the basis for sustainable coconut production, is under threat of genetic erosion due to decreasing hectarage caused by urbanization, crop shifts, and natural and human-made calamities. Many governments cannot afford to conserve their diversity. Unless farmers earned more from their coconut, they could not afford to conserve their important varieties. Many have lost interest to plant coconuts and have shifted to other crops but have met the same fate due to lack of production resources.

To help address the above problems, the International Plant Genetic Resources Institute (IPGRI) organized the International Coconut Genetic Resources Network (COGENT) in 1992. This network which started with 15 coconut producing countries as members has expanded to 38 members worldwide.

In the last 14 years, COGENT has been fully operational with 38 coconut producing member countries in five regions (South Asia; Southeast and East Asia; South Pacific; Africa and the Indian Ocean, and Latin America and the Caribbean). It has developed and promoted the implementation of coconut collecting and conservation strategies. It has successfully developed, in collaboration with the Centre de Coopération Internationale en Recherche Agronomique pour le développement (CIRAD), the International Coconut Genetic Resources Database (CGRD), which has been disseminated to coconut breeders and curators worldwide. The CGRD contains passport and characterization data (morphometric and molecular marker) and some pictures of 1416 accessions which are conserved by national programmes in 28 sites in 23 countries. To further secure and provide access to conserved germplasm, the establishment of a COGENT multi-site International Coconut Genebank has been initiated to conserve 200 important accessions in each region. The identification, characterization and promotion of coconut varieties with multi-purpose uses have been initiated in farmers' fields in 15 countries. The performances of high-yielding hybrids and farmers' varietal preferences have been evaluated in nine countries and the results will be used to help breeders in developing improved varieties. Further testing of 34 high-yielding hybrids were evaluated in multi-location trials involving three African and three Latin America/Caribbean countries to identify suitable varieties and hybrids for resource-poor farmers has been initiated. Diversity-linked income-generating activities are being used as a strategy to promote *in situ* and on-farm conservation and germplasm utilization in 15 countries. Protocols for *in vitro* embryo culture, germplasm collecting, cryopreservation, morphometric and molecular marker-based methods for locating and characterizing diversity; pest risk assessment and germplasm health management are being developed, tested and upgraded. Strategies and techniques for farmer participatory research, collecting, characterization and *ex situ* and *in situ* conservation are being refined.

To strengthen the coconut research capability of COGENT member countries, COGENT/IPGRI has organized 43 country need assessment missions and conducted 45 workshops and meetings involving 1090 coconut researchers to share information and technologies, discuss issues and common problems and opportunities and how to address them; conducted 42 training courses involving 775 participants from 41 countries; supported 288 research and training/capacity building activities in 30 countries worth US$ 2.335 million. To promote the deployment of coconut genetic resource in a wider range of coconut R&D, COGENT led the establishment of the Global Coconut Research for Development Programme (PROCORD) to an appropriate platform.

This publication describes the status of coconut genetic resources to date by documenting the work of COGENT and it partner institutions from both the developing and developed world. Chapter 1 provides an introduction of the coconut palm and describing its evolution, taxonomy, diversity and ethnobotany. Chapter 2 describes the strategies of locating diversity, the gaps in collecting and the developments on *in vitro* technique of collecting germplasm. Chapter 3 describes the strategies and initiatives in *ex situ* and *in situ* conservation and the global coconut conservation strategy. Chapter 3 describes the morphometric, biochemical and molecular methods of characterizing diversity. Chapter 5 describes the strategies and research on germplasm use, including the establishment of the International Coconut Genetic Resources Database, the use of conventional and molecular markers in coconut breeding, initiatives on breeding for drought tolerance, and the evaluation of coconut hybrids worldwide and the identification of farmers' varietal preferences. Chapter 6 describes the status of the lethal yellowing disease and the search for disease resistant varieties, the techniques for indexing and pathogen characterization, the guidelines for safe germplasm movement and the methods used in conducting pest risk assessment for COGENT's multi-site International Coconut Genebank. Chapter 7 describes the history of the establishment of COGENT by the CGIAR, its achievements in the last 14 years and its public awareness strategy to maximize its impact. Chapter 8 describes the regional research and capacity building of COGENT's five regional sub-networks while Chapter 9 contains the reports on the status of research on coconut genetic resources work in 28 COGENT member countries.

This publication is the most comprehensive report on the status of coconut genetic resources to date. It is hoped that it will be useful to researchers, policy makers and development organizations as a basis for planning and implementing research and development initiatives to promote the conservation and use of coconut genetic resources. Some of the materials in this book will also be useful to students who choose to work on coconut genetic resources and their use.

The editors

Chapter 1

An introduction to the coconut palm

An introduction to the coconut palm

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Evolution of the coconut palm

The evolutionary history of a species, which has been pressed since antiquity into the human economy, surviving as wild fragment populations in a minute number of locations, has to be necessarily highly speculative. Nevertheless, the separation of the coconut from a cluster of ancestral palms located on what later became the dispersing land fragments of the super-continent of Gondwana, and the subsequent development of a whole suite of unique and interesting features, excites the scientific imagination to wonder how nature could generate such an outcome (Foale 2004).

Through a process of natural selection, over a period of perhaps 80 million years, the coconut developed the means to disperse across vast expanses of ocean and take hold firmly on the perilous boundary between land and sea, adapting to fierce windstorms and periodic inundation, thriving unassisted by any other fauna and flora, and delivering its fruit in turn to the ocean vehicle for further dispersal.

The very components of the fruit that enabled this species to successfully conquer the open ocean and take firm hold of the land on arrival became for humans the source of nourishing food and drink, and raw materials for fuel and tools of many kinds ranging from ropes to cups and buttons. The sandy berm on the land edge of the strand (the zone between high and low ocean tides), built of sand by raging storm tides, retains little water or nutrients to support a seedling attempting to become established. The coconut evolved to defeat these environmental shortcomings by developing a huge endosperm, larger than found in any other plant with the exception of the 'double coconut' of Seychelles.

There is sufficient energy and nutrients in the coconut seed to support growth of the seedling for more than one year, providing the opportunity for the roots to extend through the berm to the underlying soil layer that is bathed by the fluctuating fresh water table, which responds to the twice daily tidal rise and fall of the ocean. The coconut is most 'at home' in an environment where the roots are thus intermittently immersed in ground water, which has accumulated the essential plant nutrients released by the decay of plant residues. The endosperm or kernel of the coconut, evolved to enable the palm to colonise new habitats, also proved to be highly supportive of human colonisation of new habitats and a subsequent major support for the prosperity of human communities (Foale 2003; Foale and Ashburner 2003).

The cohabitation of human and coconut populations ushered in a new era for the evolution of the coconut. Selection, especially for enhanced food and drink qualities, moved the coconut away from some of the critical traits that had enabled it to successfully disperse over a vast portion of the globe on a geological time scale. Before human arrival, the coconut had undoubtedly reached thousands of islands and mainland shore locations stretching over most of the tropical Pacific Ocean, throughout the islands of Southeast Asia, and probably to some shores of the Indian Ocean. It appears that the lack of an ocean current connection between the Indian and the Atlantic Oceans was responsible for the absence of the coconut on the west coast of Africa and the east coasts of South and Central America prior to its introduction from East Africa and India by the 16th century Portuguese navigators.

Taxonomy

The Cocos genus is mono-specific, showing recognition by taxonomists that it has no close botanical 'relatives'. The palm known as the 'double coconut' or '*coco de mer*' (coconut of the sea) produces a fruit that bears some slight resemblance to the coconut, however, it is many times larger and is very different for all other traits (morphology and phenology). The coconut is placed in the Arecaceae family (formerly Palmaceae) and the sub-family Cocoideae which has 27 genera and 600 species (Teulat *et al*. 2000).

The coconut has 32 chromosomes (16 pairs) and may be divided into two distinct groups - Tall and Dwarf, with a further division within the Dwarf group between forms with either fragile or robust trunks. The Tall, in general, is allogamous(out-breeding) because even though the male and female flowers are located close together on each inflorescence, the pollen is shed before the females are ready for it. The fragile Dwarf is mostly autogamous because the male flowers shed pollen freely while the female flowers are receptive. The Dwarf group that possesses a robust trunk and is less precocious that the fragile Dwarf has flower behaviour similar to the Tall. There are no reports of incompatibility between any paired individuals or populations. Tall and fragile Dwarf palms cross readily to produce vigorous and fertile hybrids.

Diversity

The confinement in nature of the coconut palm close to the strand environment described in the evolution section has placed narrow limits upon its many morphological and some phenological characters.

Successful dispersal depended upon a buoyant fruit that contained adequate kernel in the seed to ensure successful establishment. A variant that bore fruit possessing less husk might not survive lengthy immersion in the ocean without becoming waterlogged. Another variant that produced a smaller seed (nut) might contain insufficient water to last through a sea voyage to retain the vital amount needed to stimulate germination upon arrival. A thin-shelled variant might crack upon falling from the palm and lose its water, and so on. Certainly, it has been reported that some populations of putative wild coconut palms show remarkable physical similarities in fruit characters even though there is molecular evidence of wide evolutionary separation (Ashburner 1995).

The aspects of coconut phenology (development) that contribute to the success of the coconut in its unique habitat include late germination (early germination would risk the seedling emerging from the seed before the fruit fell into the ocean) and late onset of flowering. Early flowering risks diversion of growth resources from the development of a sturdy trunk and adequate peripheral roots at the base of the trunk to withstand destructive wind.

Besides these easily recognised morphological and phenological traits, there are many others that are not readily observable and that have been discovered only as a result of the movement of populations between diverse habitats. This reference to diversity of habitat is not a contradiction of the earlier assertion that the coconut is confined next to the strand. There is wide scope for variation in the shore environment already described with respect to climate – especially seasonality and quantity of rainfall, and exposure to strong wind; soil type – ranging across sands derived from coral, silica, volcanic ash or rocks and the effluent of streams and various biotic pressures especially from insects and micro-pathogens originating in adjacent vegetation systems.

It has become clear during almost one hundred years of coconut research in different parts of the world that there is great diversity for tolerance to water deficit, which is one of the most important adaptations that could contribute to improved productivity. The factors mentioned in the previous paragraph have generated diversity in the coconut through natural selection but the genetic changes have not been accompanied by the appearance of any morphological markers that could assist the observer to know that a particular adaptation is present. In the early days of coconut research, awareness of such genetic diversity came about through the observation of exotic populations in new environments.

A few examples will serve to illustrate the existence of 'invisible' adaptation in coconut. Recognition of hidden tolerance or partial avoidance of the *Brontispa* leaf beetle took place in Solomon Islands in the 1920s, when an introduced coconut population from the Federated Malay States was severely damaged in both nursery and early field stages of growth on plantations alongside the almost untouched indigenous population. In Vanuatu in the 1960s, exotic material succumbed fatally to a virus whose presence in the local Tall population was not in any way suspected, due to a lack of any observable symptoms. In Indonesia in the 1980s, many hybrids between West African Tall and Malayan Yellow Dwarf were attacked by a variant of the fungal pathogen *Phytophthora palmivora* that apparently did not harm local palm populations.

Thanks to molecular techniques, it is now possible to associate specific important adaptations with molecular markers that can be accurately identified in the laboratory. This aspect of research technology has the potential to contribute very potently to the success of future breeding endeavours based upon the screening of the assemblages of genetic material that have been gathered under the auspices of International Coconut Genetic Resources Network (COGENT). Some useful definitions to describe different groupings of genetic material, prepared by Bourdeix *et al.*, are presented in Annex 1.

There are many other examples of diversity in coconut for which morphological markers are actually present, as it was those very markers that were the traits being sought by human selection. Much of the diversity generated by human intervention is within the distinctive Dwarf sub-group of the coconut. With the exception of the robust Dwarf known as Niu Leka, all Dwarfs are almost completely obligate self-pollinators, leading to the emergence of traits transmitted by recessive genes, particularly a number of orange and yellow colour variants. These colours are particularly useful in eliminating the few hybrid seedlings that arise from uncontrolled pollination of a Dwarf palm in the company of Tall neighbours. Brown and green Dwarf seedlings can be recognised with less accuracy relying on their growth rate as an indicator of dwarfness. In traditional coconut cultures, where the Dwarf is valued for domestic use because of the relative ease of harvesting fresh fruit and the convenience of a small fruit as a source of juice, the Dwarf has been assigned an important role in homes and home-gardens.

Another result of human-managed diversity is the so-called *niu vai* or water coconut associated especially with Polynesian settlements. Whereas, the small-fruited Dwarf is seen as the preferred source of fruit for drinking in the settled environment of the village, the situation is quite different when provisioning is required for a sea voyage.

Coastal peoples are invariably mariners, maintaining skills and boats in order to trade along the coast as well as to harvest from the sea, and being prepared for longer voyages in response to invasion or population pressure. Selection of a coconut fruit suited to such contingencies would have the objective of providing the best possible source of both food and drink on the voyage. An immature fruit, such as the typical 'juice nut' has a shelf life of just a few days without refrigeration and is therefore unsuitable for a long voyage. Both food and drink can be provided, with least space required in the sea-going craft (and least weight of 'cargo' relative to the amount of vital components), by means of large mature fruit possessing a thin husk. There is evidence of selection for large fruit in many parts of Asia and the nearby island nations, and there are remnants of isolated populations of large-fruited palms on scattered islands across the Pacific Ocean. This association of diversity with specific human needs will be dealt with in more detail in the ethnobotany section below.

Ethnobotany

This section overlaps somewhat with that on genetic diversity, dealing in more depth with the targeting of specific traits selected to serve for human purposes at the local level, and also in developing or expanding a promising wider market for a coconut product.

Whereas, Dwarf populations are distinctive and uniform at the local level with respect to fruit morphology and colour, Tall populations generally look pretty much the same all over the world. Extremes of fruit size are noticeable but otherwise there is usually, within any group of palms, a great diversity of colour, fruit shape and size, whilst palm crown morphology is mostly a matter of age and nutritional status. Ethnobotanical traits (those sought by humans) are elusive in Tall palms because of the lack of markers already noted, and because of the predominant outbreeding behaviour.

Unlike inbreeding species such as wheat, rice or sorghum for example, where the selection of a distinctive individual plant offers the opportunity for the traits of that plant to be preserved securely in its progeny, in the Tall coconut a valuable trait identified in a single palm can prove difficult to multiply because of the genetic diversity in which it is embedded. Preservation of traits is much simpler in the Dwarf, suggesting that effort might be made to assist in the transfer of particularly interesting traits such a special aroma, or edibility of the immature husk, from Tall to Dwarf.

In general, the coconut is not rich in distinct ethnobotanical traits that are of great commercial value. The relative genetic uniformity of the species compared to most crop plants that have emerged from regions that encompass great biophysical diversity confines coconut to a narrow range of variants. Little variation in the qualities of the fibre, shell, kernel and water has been demonstrated. There is on the other hand great ethnic diversity in the ways that the various coconut resources are produced and used. It is ethno-industry more than ethno-botany that gives rise to the great range of products derived especially from the fibre and shell including exquisitely crafted works or art and many materials of great commercial value.

Distribution

The natural dispersal of the coconut prior to the colonisation of the entire planet by humans has been dealt with above, but the historic distribution that was limited by the 'reach' of viable seeds floating on the ocean has been enormously expanded in recent millennia. Expansion inland from the natural coastal 'foothold' has been responsible for a great increase in coconut populations as human populations grew, and there has also been, quite recently, expansion to new lands previously not colonised by the wild coconut.

An interesting aspect of coconut distribution arises from the evidence of widespread 'invasion' of natural coconut habitats by human settlers. Many coconut populations exhibit a degree of shift from the characteristics of formerly wild coconut populations (attributed to introgression between two populations of different origin – the wild one and the introduced one) that would have taken many generations to achieve.

Except for a small number of atolls, where human settlement apparently never took place, or where it was very recent indeed (as for example the Cocos (Keeling) Islands settled in 1827), coconut populations from Asia to the eastern Pacific show signs of introgression between wild and 'domesticated' variants. The degree of drift in fruit morphology away from the classical wild traits varies greatly, being most marked in some relatively isolated Polynesian islands such as Rennell in Solomon Islands and Rotuma in Fiji Islands. It is likely that the wild population of coconut palms before the arrival of the Polynesian colonisers (which is known to have been at least 1000 years ago) was quite small, as the rocky coasts of these two islands possess only a few sandy berms where wild palms would have been growing. The genetic traits of the palms planted by the colonisers therefore became dominant within a few generations through a combination of relatively little dilution by the wild genotype and purposeful selection by the people.

The final 'coconut-free zone' of the earth, being the tropical shores of the Atlantic Ocean, was 'invaded' very early in the 16^{th} century by the introduction of seeds from the Indian Ocean shores, brought there by Portuguese navigators returning from voyages in the Indian Ocean. From a base in the Cape Verde Islands (close to the coast of Senegal), seeds were distributed within a few decades to all the new colonies in the tropical Americas. However, there was already a coconut population on the Pacific coast of Central America with nut characters inconsistent with dispersal from the ocean. One could speculate that the seeds which founded that population had originally arrived by boat prior to the entry of European navigators into the Pacific, from a source in Polynesia.

By the end of the 16th century, the coconut could be found throughout the tropics with one notable exception. The tropical coast of Australia was as yet unknown to European navigators, but even when it was charted – mostly in the early 19th century - there was no sign of the coconut palm. A tiny population was later found (in 1848) on an offshore island, during intense local mapping of the northeast coast and the barrier reef. The possible reasons for this strange absence could be attributed to a combination of the consumption of drifted fruit for food by both native people, and also by a particular species of native rat capable of opening a mature fruit with ease (Foale 2003).

The coconut can now be found on practically every suitable tropical and sub-tropical coastline worldwide, and has been transported far from the coast in many regions, wherever rainfall is adequate and the altitude does not exceed 1000 m. Although one would expect a species whose native habitat is at the very edge of the ocean to be "ecologically challenged" elsewhere, the coconut has shown a remarkable capacity to thrive on soil textures that range from coarse sand, like that of the berm on the coast, to heavy-textured clay. Certain essential nutrients constrain success of the coconut by their absence, and particular mention should be made of chlorine because its importance to the coconut is less well known compared with the usual major nutrients. Whilst chlorine is generally abundant near the coast, there are many sub-coastal and inland areas where the leaching action of intense rainfall has reduced chlorine availability to the point where it limits coconut growth.

In the era of great industrial use of the coconut, commencing in the middle of the 19th century, coconut distribution became much broader as plantations were successfully established on hundreds of thousands of hectares of land previously occupied by rainforest. Provided that the annual rainfall totalled at least 2000 mm, and the season of severe water deficit did not exceed three months duration, the coconut prospered. Many biotic and nutritional challenges were encountered away from the coast but in general, these were overcome and the plantations were productive and profitable for up to 100 years. It has been economic rather than ecological factors that have placed constraints on the distribution of the coconut in recent decades.

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Annex 1. Useful definitions of terms and nomenclature

by R Bourdeix, G Santos, JP Labouisse and L Baudouin

Cultivar/Variety/Ecotype/Population/Variant

Definitions:

'True' variety: from a strict botanical point of view, there are only three main varieties in coconut:

- Tall : high height increment, spaced leaf scars, predominantly allogamous, late bearing.
- Dwarf: reduced height, narrow spacing between leaf scars, predominantly autogamous, precocious.
- A few intermediate and other types of coconut, such as Niu leka Dwarf (Polynesia) and King Coconut of Sri Lanka.

Cultivar: 'Cultivated variety' is defined as a group of individuals or plants having similar traits that can reproduce "true-to-type" in the natural (sexual) way from generation to generation.

Ecotype: Individual plants or populations which survive as a distinct group through environmental selection and isolation and that is comparable with a taxonomic species.

Comments: The focus here is on the words: survival, environment, diverse. In most cases, it seems to be difficult to qualify coconut cultivars as true 'ecotype'. Some possible exceptions are cultivars found in atolls and other environmentally very particular conditions. Vanuatu Tall, for instance, the only cultivar resistant to the foliar decay virus, can be considered as a true ecotype (this is a special case where a pathogen is given the status of a major ecological influence, yet it is a factor that could be eliminated).

Population and **variant:** This can be considered as similar in connotation and would refer to a group of individuals obtained from a cultivar. Population refers to any subgroup located in a restricted location, such as one island, atoll or continuous strip of coastline. Variant is narrower than that in the sense that members of the group exhibit a specific trait as stated below.

Variant could be preferred for special botanical types which may be found in different cultivar: Makapuno/Kopyor/Coco Gras/Dikiri or Spicata.

Populations could denote minor geographical and/or phenotypic differentiation within a cultivar. (Population could also refer to palms in a location, whether they be highly heterozygous, as most Tall populations are, or homozygous, as in the self-pollinating Dwarfs).

Unfortunately, experience shows that most non-scientific observers and stakeholders do not know or do not appreciate the term "Cultivar". They frequently use the term 'variety' instead of 'cultivar'. Even in many scientific papers, 'variety' remains and used in place of 'cultivar'. The scientific community has to make an effort to be understood through better communication with the rest of the world. So assuming that the terms of 'cultivar' and 'variety' are mostly synonyms, the following examples can be proposed:

"True" varieties:
- Tall : rapid height increment, widely spaced leaf scars, predominantly allogamous, late flowering and bearing.
- Fragile Dwarf: reduced height, narrow spacing between leaf scars, trunk diameter about 40% less that Tall, little of no basal bole, predominantly autogamous, precocious (early flowering and bearing).
- Robust Dwarf: Very low rate of trunk extension, trunk diameter and flowering behaviour similar to Tall, crown more compact than that of Tall or Fragile Dwarf

Cultivar or Variety : West African Tall, Catigan Green Dwarf, and Vanuatu Tall which could also be considered an **Ecotype.**

Population: WAT06 (West African Tall *Ouidah* from Benin)

Variant: Makapuno (Philippines), Dikiri (Sri Lanka), Spicata (different countries), Nawasi (Sri Lanka), Nim (Thailand)

Sub-population: **I**ndividual plant/palm

Chapter 2

Locating and collecting germplasm

Locating coconut genetic diversity

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Introduction

Cocos is a genus in the family Arecaceae (Palmaceae), subfamily Cocoideae, which includes 27 genera and 600 species. Distributed mainly in coastal regions between 20° N and 20° S, from sea level to 1000 m asl, the coconut – *Cocos nucifera* L. (2n = 2x = 32) – the only species in the genus, is an important perennial tropical plantation crop with no known truly wild forms.

The variability of local coconut types is reported to be highest in Southeast Asia (Whitehead 1976). However, it has not been possible to establish either a true centre of diversity or centre of origin for the species. These simple but basic factors are of great importance for understanding the extent and distribution of coconut genetic diversity and for locating useful variation.

In 1992, the International Plant Genetic Resources Institute (IPGRI), with the endorsement of the Consultative Group on International Agricultural Research (CGIAR) and its donors, established the International Coconut Genetic Resources Network (COGENT) with the aim of promoting an international collaborative programme on the conservation and use of coconut genetic resources. Collecting, conserving, evaluating and enhancing coconut germplasm of member countries, and locating and characterizing genetic diversity using morphometric and molecular biology techniques, have been some of COGENT's major concerns (http://www.ipgri.cgiar.org/networks/cogent). Under the auspices of COGENT, the activities related to genetic resources collection and genetic diversity in coconut have been streamlined and significant progress in these areas has been made.

Genetic diversity

Genetic diversity is usually thought of as the amount of genetic variability among individuals of a variety, or population of a species (Brown 1983). It results from the many genetic differences between individuals and may be manifest in differences in DNA sequence, in biochemical characteristics (e.g. in protein structure or isoenzyme properties), in physiological properties (e.g. abiotic stress resistance or growth rate) or in morphological characters such as flower colour or plant form (Ramanatha Rao and Hodgkin 2001). Four components of genetic diversity can be usefully distinguished; the number of different forms (alleles) ultimately found in different populations (sometimes referred to as 'richness'), their distribution (or 'evenness'), the effect they have on performance (related to population density) and the overall distinctness between different populations. The variation that underpins genetic diversity arises from mutation and recombination. Selection, genetic drift and gene flow act on the alleles present in different populations to cause variation in them. The selection can be natural or it can be artificial, as is the case with much of the variation present in crop species (Suneson 1960; Frankel 1977; Nevo *et al*. 1984; Brown 1988; Hamrick *et al*. 1992). It allows species and populations to adapt to changing conditions and provides the basis for the observed differences between different ecotypes, populations or cultivars of coconut.

It is generally accepted that the genetic variation in plant populations is structured in space and time (Loveless and Hamrick 1984). The description of the extent and distribution of the different aspects of genetic diversity in a species, and of the way in which it is structured, is an essential prerequisite to determining what to conserve, and where and how to conserve it. To date, most conservation efforts, either *in situ* or *ex situ*, have proceeded with little information on the genetic diversity that was being conserved and on what part of the total genetic diversity of a species this constituted. There is an urgent need to remedy this situation by describing the variation observed and identifying the factors likely to affect its distribution. Such factors often include climatic, edaphic and biotic ones as well as those specific to the populations (e.g. population size, selection) or to the species (e.g. ploidy, breeding system, linkage).

Where data is available at the genetic level, e.g. from DNA or isozyme studies, direct measures of richness, evenness and distinctness may be obtained (Nei 1973). However, when dealing with morphological data, direct estimates of numbers and distributions of genes or alleles are hardly obtained and analyses of diversity are based on statistical parameters such as means, ranges, standard deviation and variance. Nonetheless, descriptions of morphological characteristics and reactions to pests and diseases of a population, local cultivar or accession remain the most useful information for plant breeders, agronomists and other users. Although these are often obtained in ways that make formal analyses of the extent and distribution of genetic diversity difficult, the information can often provide useful guidance on location of variation of particular characteristics. It can also be combined with other more formal analyses to provide an overall view of the ways in which different components of diversity are distributed.

Coconut genetic diversity: General considerations

Coconut is one of the few major crop species that has no closely related wild relatives. Coconut belongs to the palm family (Palmae or Arecaceae), which has about 2800 species of 190 genera. The Cocoeae tribe with 27 genera and nearly 600 species includes several economically important plants such as *Cocos nucifera* (coconut), *Elaeis guineensis* (African oil palm), *Attalea cohune* (babacu) and *Bactris gasipaes* (peach palm). Palm species most related to the coconut palm are found in Colombia (Cook 1901). However, there appears to have been no possibility of mating or gene exchange with any related species and all coconut cultivars constitute a single potentially freely intermating genepool. Since coconut is an ancient species and has been under cultivation for several thousand years, it is reasonable to presume that early humans, while developing habitats in coastal areas, must have slowly domesticated any wild form that was present. Current theories mainly suggest that it must have originated in the Indonesian Islands and later spread to become pantropical, although the date of its spread to the Pacific has been under considerable debate (Harries 1990; 1995). It is also reasonable to presume that the spread of coconuts was based on small initial sample size, considering the bulk of the seed material. If the theory about its spread by flotation is true, then the sample size might be limited to one or two nuts and this is especially so in coconut populations found on the mostly uninhabited small islands and atolls. Thus, the bottleneck processes through which the coconut must have undergone through its world-wide spread, either human-assisted or otherwise, may well have resulted in considerable genetic drift in the founding populations. These observations have a significant bearing on the current genetic structure of the coconuts. In order to understand the process of spread, further studies on the historical and pre-historical knowledge of coconut are needed. Current knowledge appears to be weak in many countries and there has been no attempt to carry out a thorough check of the world literature relevant to this subject as suggested by Bourdeix *et al*. (1999).

Although it has been generally agreed that humans must have domesticated the coconut in pre-historical time, it is not clear what was the domestication process involved and how the species evolved under domestication, as there are no 'wild' coconuts for comparison. The nature of selection pressure that farmers might have applied is difficult to comprehend taking account of the perennial character of the species. In many cases, there could be more than one human generation in the life of a coconut palm. This leads to difficulties in trying to determine the farmer practices and their effect on the constitution and characteristics of local populations. This is further complicated by the fact that farmers are unlikely to have replaced individual coconut trees in their prime, let alone a whole orchard or population, with another crop or improved genotype, unless such substitution brought enormous benefits or they were forced to take such measures by external circumstances. This suggests that complex evolution of the different types or genotypes of coconut (with more and less desirable coconut types occurring together) may have been a quite common feature of coconut populations. This would lead to highly heterogeneous populations in which there could have been substantial. Thus the genetic structure of coconut could be fairly complex even if the frequent bottlenecks might result in populations with reduced genetic diversity in individual populations than what occurs in other perennial species that have undergone similar process of evolution, with less stringent bottlenecks.

Guarino *et al*. (1998) suggested that the key features of coconut evolution might be summarized as follows:

- Populations initially established by few individuals (founder effect, genetic bottleneck), but often from a variety of sources.
- Low but continuing levels of gene migration among wild-type, feral or semi cultivated populations.
- High levels of outcrossing within populations.
- Selection by local communities, and movement of domesticated germplasm to Africa and the New World.
- Continuing introgression of selected local varieties with wild-type populations and hybridization among domesticated varieties.

The result, as revealed by genetic diversity studies using a range of morphological, physiological, agronomic, biochemical and DNA characters (see below), is that every region or large island has more or less distinctive populations, (commonly described as ecotypes). Tall ecotypes are highly variable (about 60% of the total diversity is found within Tall ecotypes in the Pacific), while Dwarfs are less variable, probably reflecting the fact that they are autogamous. The distinction between Tall and Dwarf types (which is really a difference in precocity) is sometimes formalised into botanical varieties *typica* and *nana*, but the taxonomic validity of this is not universally recognized. Although variation among ecotypes is basically continuous, regional Afroindian, Southeast Asian and Polynesian groupings can be recognized. Sub-groupings are also recognized within the Polynesian germplasm, in particular South Pacific, Northeast Pacific and Marquesas-Hawaii groupings, with the Rennell Island population relatively isolated.

Morphometric studies of diversity

A description of the morphological characteristics and reaction to pests, diseases and stresses of an accession are the most useful information to plant breeders and other users. Such data (in conjunction with locality data) can be used in identifying especially diverse areas and those where specific traits can be found, and in exploring the relationship among accessions. However, using morphological characterization data for locating diversity has a number of limitations. Differential heritabilities, pleiotropic and epistatic effects, polygenic control and genotype x environment (G x E) interactions that are often associated with morphological characters can make estimation of genetic variation difficult. In many cases, long-term crossing and inheritance studies will be needed for precise estimation. There is also the problem that most genetic variation is hidden and is not apparent at the phenotypic level, so that morphologically similar material may in fact be genetically quite different. Despite these drawbacks, morphometric methods have been used to advantage in coconut as well as other crops (N'cho *et al.* 1993; Akpan 1994; Sugimura *et al*. 1997; Ashburner *et al*. 1997).

The first publications comparing a large amount of data gathered from coconut accessions came from Africa. The description of most of the accessions from the collection at the Marc Delorme Station (Ivory Coast) has been reported in numerous publications (Nuce de Lamothe and Rognon 1977; Nuce de Lamothe and Wuidart 1979 and 1981; Le saint *et al*. 1983; Sangare *et al*. 1984; N'Cho *et al*. 1988). However, each of these publications produced in a series covered only a limited number of accessions, generally four to six, always compared with West African Tall (for Tall types) or Malayan Yellow Dwarf (for Dwarfs) used as reference controls. Using the same data, 17 Tall coconut ecotypes were assessed taking a biometric approach with the use of 24 major morphological descriptors. A discriminant analysis revealed the relations existing between ecotypes. The resulting dendrogram groups together accessions to the extent of their similarity into nine groups of 1 to 3 (N'cho *et al*. 1993).

Sugimura (1997) carried out a genetic diversity study using botanical and agronomical traits on 39 cultivars of coconut palms which were mainly collected in the Philippines, and statistically analyzed to clarify the variation between and within cultivar groups (*typica*, *nana* and *javanica*). Although there were broad variations in all the traits except for several male flower characters, significant differences among the three cultivar groups were found in a dozen of traits. The variation within a cultivar group was higher in *typica* and *javanica*. *Nana* was noted as an aggregate group, which was distantly far from *typica*. *Javanica* was characterized as the intermediate group having overlapping boundaries with other groups. As noted earlier, although these are not valid taxonomic classes, they seem to be useful for morphological groupings of cultivars.

Zizumbo-Villarreal (1998) studied the pattern of morphological variation of coconut in Mexico. They analyzed 41 populations using 17 morphological fruit characters. Principal component and cluster analyses indicated four main groups of coconut populations that showed high similarity with four different genotypes recently imported into Mexico from areas that could be the origin of Mexican coconut populations. These four genotypes were evaluated with regard to lethal yellowing disease in Jamaica and showed a differential susceptibility. Based on the difference in susceptibility of the Mexican genotypes, the analysis of correlation between morphological and geographical distances showed a high positive correlation that supports: 1) historical evidence that indicates early introductions of coconut from different regions of the world, and 2) that on both coasts of Mexico two different patterns of dispersal were involved - continuous and in jumps. It was concluded that collectively these results suggest that the impact of the lethal yellowing disease on coconut populations will vary depending on the specific area and the origin of its coconuts, although it is not very clear how this conclusion could be drawn. This will require some level of follow up.

Vargas (2000) evaluated Tall coconut cultivars from the Pacific coast of Costa Rica and the Philippines (San Ramón, Tagnanan and Laguna), for fruit characteristics. Most of the introduced cultivars showed extremely large heterogeneity. A cluster analysis, based on the Ward method (Ward and Neel 1970), classified the palms into four groups with high internal homogeneity. Some of the evaluated coconut palms from the Costa Rican Pacific area had nut characteristics similar to San Ramon (Group 1: large and elongated nuts) and Tagnanan palm (Group 4: heaviest fruits and nuts) groups but not with the Laguna group (Group 3: rounded and small-sized nuts). At the association level used (semipartial R2 = 0.10), another group (Group 2: small size and mildly elongated nuts) that included the remaining palms sampled from the Costa Rican Pacific Coast (Group 2: small-sized mildly elongated nuts) was constituted, thus showing that the Costa Rican types were different from the established cultivars (for detailed treatment, see Baudouin and Santos, Chapter 4).

Use of Isozymes

This method of genetic variability evaluation is barely developed for coconut. The initial study, undertaken with pollen involved nine enzyme systems (Benoit and Ghesquiere 1984; 1989). After several technical difficulties, only four systems were used to compare eight ecotypes:

Malayan Yellow Dwarf (MYD); Cameroon Red Dwarf (CRD); Pumilla Green Dwarf (PGD); Niu Leka Dwarf (NLA); West African Tall (WAT); Malayan Tall (MLT); Tahiti Tall (TAT) and Vanuatu Tall (VTT). The eight ecotypes showed a weak enzyme polymorphism, few polymorphic loci per system, and never more than two alleles per locus. The intra-ecotype variability was low for autogamous Dwarfs, higher for the Niu-Leka Dwarf and the Talls, with the exception of the West African Tall, which was monomorphic for the four enzyme systems tested. The low enzyme polymorphism of coconut contrasts with the morphologic diversity within the species and suggests that the marked phenotypic differences could hide homologous genetic structures. The apparent absence of variability in WAT is possibly due to successive bottlenecks in its spread that have led to a high level of consanguinity. Other studies of patterns of isozyme variation were also conducted in Sri Lanka (Fernando 1995) and Indonesia (Asmono *et al.* 1993) with rather similar results.

Villareal *et al.* (2002) studied the diversity of 22 populations of Mexican coconut and six imported populations using 15 enzymatic systems and the allele frequencies in: peroxides, endopeptidase, glucose 6-phosphate dehydrogenase. They observed very low polymorphism, not more than two alleles per locus. The Wright fixations indices, F(it)= 0.62, F(is) = 0.40 and F(st) =.036, indicated low total heterozygosity and low heterozygosity within populations suggesting inbreeding and genetic drift and a high diversity among populations due to differentiation between Pacific and Gulf of Mexico coastal populations. The phylogenetic tree with values for genetic distance, indicated three groups on the Pacific coast related to Rennell Tall and Polynesian Tall, and two groups on the coast of the Gulf of Mexico, one related to the West African Tall and the other to Mexican Pacific coast populations. This corroborated historical antecedents and morphological and physiological patterns. The Dwarf coconuts were related to the Pacific Tall populations, Rennell Tall and Polynesian Tall. There was no difference between local and imported Dwarf populations.

Cardeña *et al*. (1998) determined electrophoretic patterns of leaf peroxidases, endopeptidases, and Coomassie blue stained proteins were analyzed in four cultivars (West African Tall, Rennell Tall, Malayan Yellow Dwarf, Cameroon Red Dwarf), and in the hybrids PB121 (MYD x WAT) and PB111 (CRD x WAT). Polymorphisms were detected for the expression of two alleles of a dimeric peroxidase, two alleles of monomeric endopeptidase, and a pair of active null alleles of a dimeric peroxidase, two alleles of Coomassie blue stained protein. Four distinctive genotypes were identified, one for each of the Tall cultivars, another for both of the Dwarf cultivars, and the last for both of the hybrids.

Use of polyphenols

The analysis of the polymorphism based on the analysis of leaf polyphenol using High Performance Liquid Chromatography (HPLC) provided an original approach to the study of genetic diversity in numerous plant species. The first analysis on coconut has involved the measurement of 16 sufficiently individualized peaks or major items of chromatographic information, each corresponding to a molecule or a few molecules of strong structural affinity (Jay *et al*. 1989). From 32 ecotypes, 171 palms were sampled in the collection of the Marc Delorme Station in Côte d'Ivoire. The data were subjected to multivariate analysis. The first discriminant analysis showed a clear distinction between Dwarfs and Talls. Only 19 out of 171 individual palms showed atypical behaviour. Certain Tall trees of various ecotypes behaved like Dwarfs: AGT, MLT, RGT, TAGT, RIT, TAT, WAT, PNTO1; while one NLAD tree behaved like a Tall. Most Dwarfs presented common characteristics that clearly distinguished them from Talls as shown in the morphologic and polyphenol analyses.

The second analysis consisted of a canonical analysis per ecotype. Data analysis favoured the differences between ecotypes at the expense of intra-ecotype variability. Classification within this analysis was not based on geographic groups; the image obtained, however, permits such an interpretation. Five groups were recognized to classify the collection of the Marc Delorme station: Pacific, Far East, Indian Ocean, Africa and America, the last one being represented by only one ecotype. Among the Tall ecotypes, the representation permitted the determination of three distinct groups corresponding to the Pacific, the Far East and Africa. The ecotypes of the Indian Ocean may be divided between the African and the Far East groups. Certain points precisely strengthen the historical hypothesis. The Ghana Yellow Dwarf (GYD) and Malayan Yellow Dwarf (MYD) are very close, confirming the old hypothesis that the Yellow Dwarf was introduced from Malaysia into Africa during the time of the British colonial rule. Anyway, with the advent of DNA marker technology, the characterization of genetic diversity in coconut germplasm at the DNA level has recently begun to substitute other strategies like isozyme or leaf polyphenol analysis.

Molecular studies of diversity

The use of molecular techniques in studying genetic diversity in recent years has contributed to better understanding of the genetic diversity of some species (Karp 2002; Hodgkin *et al*. 2001). The increase in the use of molecular techniques in genetic diversity studies is based on the facts that:

- Appropriate molecular markers can provide direct estimates of gene and allele frequencies and can detect whether plants are homozygous or heterozygous for given markers;
- Molecular techniques make it possible to analyze numerous and independent characters, whereas morphological analysis provides fewer characters, often of dubious homology;
- Morphology is prone to considerable convergence while most DNA regions are less so and even if there is some convergence, the genetic basis of convergence in molecules is better understood; and
- Molecular markers are relatively independent of the environment (Beckmann and Soller 1986).

It has been argued that molecular markers provide a particularly powerful approach to understanding patterns of distribution of genetic diversity that can be used to adjust collecting, evaluating and breeding strategies so as to obtain maximum variation from any given wild population (Morikawa and Leggett 1990). However, it has also been noted that molecular methods should not be used on their own. Thus, Ashburner (1994) emphasized that DNA analysis should not replace currently used characterization methods, but should be used as adjunct when formulating conservation and crossing strategies. Analysis of data can distinguish similarities or differences between coconut populations and thus can be used to prevent duplication in conservation blocks and crossing programmes. However, if two populations appear similar, major adaptive genes may still exist and these may not be picked up by molecular studies. Therefore, collecting priorities should still take account of the need to sample unique environments. Where differences are detected by molecular techniques, there is a greater probability of the presence of different genes resulting from genetic drift, and priority should also be given to their collection.

The information from molecular marker studies can also help improve utilization of diversity in coconuts. The data can assist in setting priorities for crossing programmes allowing breeders to maximize genetic distance and take advantage of any heterosis that may occur. Markers can also be used to tag important genes and allow the use of marker-assisted selection.

For details on use of molecular markers, see Lebrun *et al.*, Chapter 4.

Improving location of diversity

A molecular marker kit for COGENT partners

Sampling, collecting and maintaining coconuts have always raised substantial logistical problems. The development of *in vitro* collecting techniques helps deal with the physical problems of collecting large nuts but the logistical requirements still remain labour intensive and expensive. Currently, fruit component analysis coupled with observing a few other characteristics at the time of collecting are used to get some idea on the population variability at the time of collecting (see Bourdeix *et al*. in Chapter 2). However, this approach does not really give a measure of the genetic diversity that is being sampled.

It was argued that molecular methods based on field collected tissue samples (Adams 1992) provided an efficient way of optimising the diversity collected and minimizing the numbers of new samples that had to be maintained in field gene banks. For this reason, over the last few years, COGENT and a number of other donors have supported the development of a molecular marker kit for coconut.

The Bureau for the Development of Research on Tropical Perennial Oil Crops (BUROTROP) and IPGRI/COGENT supported the research by Centre de Cooperation Internationale en Researche Agronomique pour de Developpment (CIRAD) France, with participation from IACR Long Ashton (UK), on developing a microsatellite marker kit and dedicated software for developing countries. As a result, the kit, consisting of 14 microsatellite loci, was developed and tested on 681 coconut palms representing a large range of diversity. A statistical method was devised to identify any small set of individual palms of the same, unknown origin. The method allows the user to compare this sample with a set of reference populations and to rank these populations in order of decreasing probabilities of being the origin of the sample. It is a very efficient tool for diversity studies and identification of germplasm accessions. The transfer of this technology to the countries where the coconut germplasm collections are located will improve efficiency and reduce the cost of conserving, characterizing, managing and utilizing germplasm accessions for breeding improved varieties (see also Chapter 4 by Lebrun *et al*.).

To downstream this technology to developing countries, 18 trainees from Brazil, India, Indonesia, Papua New Guinea, Mexico, Côte d'Ivoire, the Philippines, Portugal and Tanzania participated in a workshop on "Coconut Genetic Resources Management Using a Microsatellite Kit and Dedicated Software" held at CIRAD in Montpellier, France on 15-24 April 2002. Specialists from CIRAD managed the workshop while other specialists from partner institutions, consisting of nine molecular biologists and nine collection managers (representing a team of two participants per country) participated in the activity. The workshop was supported by IPGRI/COGENT, Common Fund for Commodities (CFC), the European Union, BUROTROP and CIRAD.

Thus, there is now a tool kit available for estimating the genetic diversity prior to collecting to facilitate the locating of germplasm and make appropriate conservation decisions including the identification of on-farm conservation sites.

Using GIS tools

A Geographic Information System (GIS) may be defined as a database management system which can simultaneously handle spatial data in graphics form - i.e., maps, or the 'where' - and related, logically-attached, non-spatial, attribute data - i.e. the labels and descriptions of the different areas within a map, or the 'what' (Guarino *et al*. 2001). It is a tool for managing information of any kind according to where it is located (Treweek 1999). The main elements of a GIS are as follows (Guarino 1995; Guarino *et al*. 1999):

- Data input, verification and editing
- Data storage, retrieval and management
- Data manipulation and analysis
- Output

If we have georeferenced information on some level of genetic diversity of coconut based on the characterization and evaluation, including molecular evaluation of the available genetic resources, it would be possible to predict where additional genetic diversity could exist using GIS tools. GIS tools will not be able to measure genetic diversity but will be able to help locate new areas where coconut diversity might exist or the areas for extension of coconut cultivation. This is somewhat a refined way of using pre-existing information. To support this type of analysis, IPGRI and the International Potato Centre (CIP) have collaborated in the development of a software called DIVA-GIS, which calculates diversity indices for all the cells in a user-defined grid given latitude, longitude and characterization data for a set of accessions, and maps the results. They have recently trained a number of plant genetic resources (PGR) workers using this technology. It is expected that new areas of coconut genetic diversity would be located using this technology in the near future. Preliminary studies, using existing data in the Coconut Genetic Resources Database (CGRD) and the specialized GIS tools (FloraMap and DIVA-GIS), have been carried out to map the diversity collected, from different COGENT member countries as well as for diversity analysis for certain important morphological traits and for prediction of similar sites where similar diversity may exist or the sites for coconut cultivation (Prem Mathur 2003, pers. comm). Using these GIS tools, one can also generate climatic database for individual collecting sites and the climatic grids for temperature, precipitation and elevation. Some of the examples are presented in Figures 1 and 2.

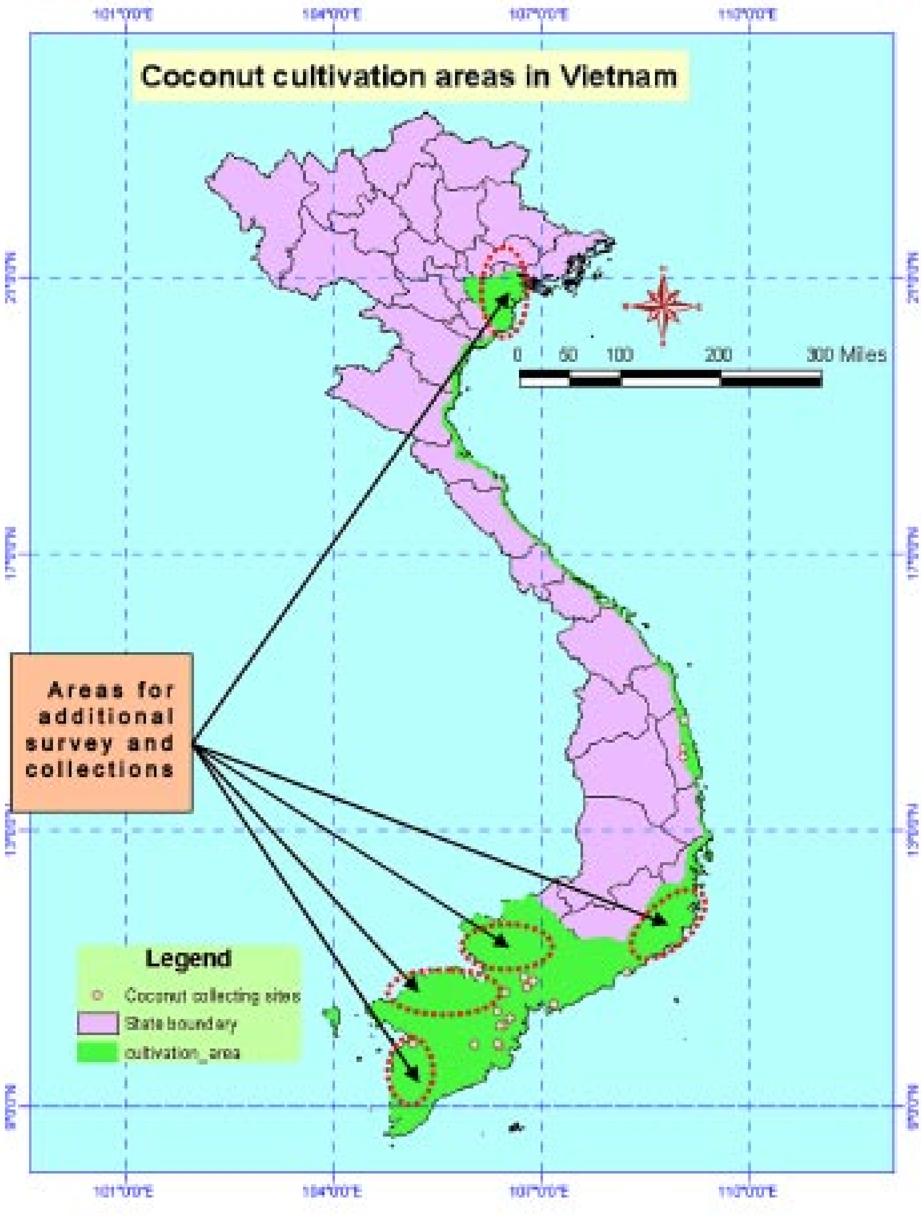

Figure 1. Mapping of major coconut cultivation areas, coconut collecting sites and gaps identification in coconut collections in Vietnam

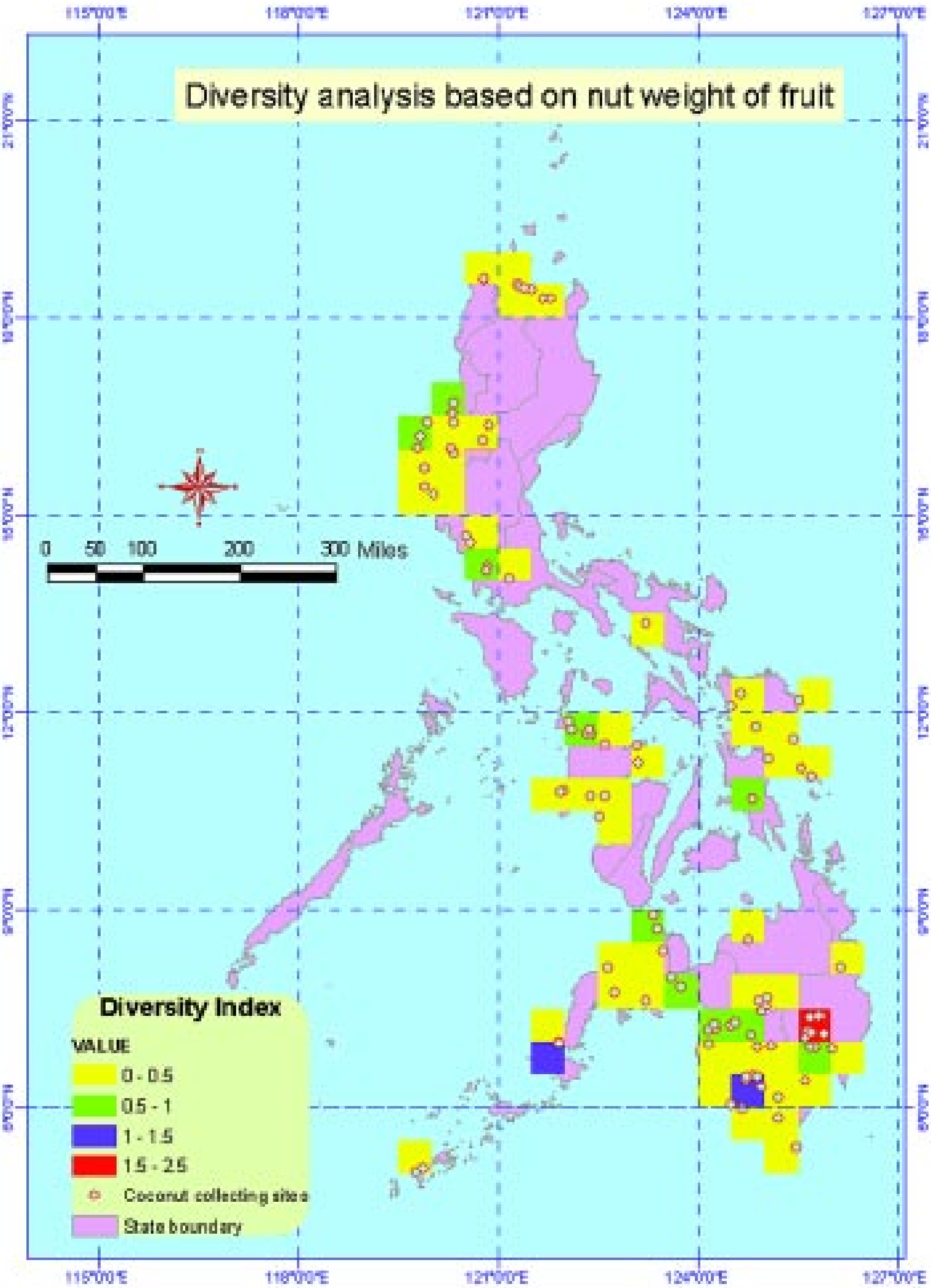

Figure 2. Mapping coconut diversity for nut weight in the Philippines

Figure 1 presents the mapping of major coconut growing areas and the coconut collecting sites in Vietnam, from which one can easily visualize where the gaps are in their coconut collections and can plan accordingly for more collections from those areas, which have not been surveyed earlier.

In Figure 2, using GIS tools to calculate trait location-specific diversity, enabled the identification of sites with high diversity grids where recollecting could be done.

Additional historical information on the movement of people, especially ethnic minorities, could provide additional information on genetic diversity as agricultural practices followed (including farmers' selection) are closely linked to ethnic origins of a community. Quite often, the ethnic composition of the population is a very important factor to be taken in account for locating diversity. For instance, the islands of Rennell, Bellonna and Rotuma are the only 'Polynesian' Islands of the 'Melanesian' archipelago (Solomon and Fiji) and these islands have provided very important coconut varieties. Bourdeix *et* al. (1999) recommended that the Farmer Participatory Method (FPM) be used by following a grid based not only on the geographical aspect but also the ethnic aspect. For example, People of Ko Samui Island in Thailand came long time ago from Hainan (China) which is famous for its coconuts and it would be possible that this community in Thailand could be maintaining coconut growing tradition. Additional survey or FPM should be conducted also in Ko Samui Island.

Conclusion

Locating, maintaining and using genetic diversity of coconut present substantial challenges given the wide dispersal of the species, the limited knowledge of the history of that dispersion and of the current extent and distribution of diversity. The logistical problems conservers and users face when dealing with a perennial species with large recalcitrant seeds added to the complexity of managing coconut germplasm. However, in recent years, substantial progress has been made, at least in part, through the strong support of COGENT partners by establishing an effective framework of knowledge on which to base their activities.

Certain general features of the species seem to be important in understanding the picture that is emerging from recent studies. These include the lack of a related wild genepool, small founding populations, human involvement in the selection and spread of the species/cultivars, outbreeding and intercrossing among populations of Talls and low but continuing gene migration among wild type or distant populations. These characteristics provide a general framework for analyzing the data that are currently coming from molecular studies. Clear differences are emerging between groups of ecotypes and populations from different areas and expected patterns of migration and transfer are being better described and understood.

Further, detailed studies are needed, particularly in high diversity areas. These should focus on ecogeographic aspects of the distribution of diversity and on the location of populations and ecotypes with unique useful traits such as resistance to biotic and abiotic stresses. The use of general, commonly agreed procedures that COGENT has developed and made available will be important to maximize the value of this new information for users and to safeguard the resources needed by poor farmers who still depend for coconut for much of their livelihood.

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Mapping of coconut genetic diversity

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Introduction

Mapping of coconut genetic diversity means representing any characteristic of coconut populations on maps, be it their phenotypic or molecular traits; and then studying the links between these traits and any other useful spatial information. According to the needs, the cultivars may be related to their site of origin or to the genebank where they are conserved. This type of analysis can improve the effectiveness of collecting, conservation, management and use of coconut genetic diversity.

The mapping studies conducted so far have used data on accessions already collected and conserved in germplasm banks around the world. The latitude and longitude of collection sites have been entered into databases and checked. Then the localities of collection sites are mapped to locate under-represented areas, i.e. areas in which the coconut palms can potentially grow, but where collecting has been inadequate or has not occurred at all. Subsequently, it is possible to identify hotspots of diversity and investigate the geographic distribution of specific traits or combinations of traits using information such as characterization and evaluation, including molecular markers, of the available genetic resources.

Georeferencing coconut accessions

From 1995 to 2002, coconut researchers of Brazil, China, India, Indonesia, Ivory Coast, Jamaica, Mexico, Papua New Guinea, Philippines, Sri Lanka, Thailand, Vanuatu and Vietnam were trained (Bourdeix 1996; 1997a; 1997b; 1998; Bourdeix *et al*. 1999; Baudouin 2002) in gathering and inputting data into the Coconut Genetic Resources Database (CGRD) (see Hamelin *et al.,* Chapter 7). Most of the determination and recording of the geographical location of the collecting sites were done in the framework of this work (Bourdeix *et al*. 1999).

This preliminary work was conducted without any sophisticated geographical information system (GIS). It consisted mainly in marking sites of collection by hand on easily available commercial hard-copy maps, preferably with the aid of the researchers who were in charge of the collecting in each country.

The method of linear approximation was used to determine, as precisely as possible, the longitude and latitude of each collection site on the maps. Later, the Encarta electronic atlas was also used to obtain geographic information more quickly. All the data were systematically entered into the CGRD and then extracted for further geographical analysis.

Table 1 presents the status of the geographical localization of coconut accessions according to countries of conservation in the CGRD (version 5.0, December 2002).

Table 1. Georeferencing of coconut accessions in CGRD (version 5.0)

Country	Number of conservation sites	Total number of coconut accessions	Number of accessions with geographical coordinates	Percentage of accessions with geographical coordinates
Benin	1	4	4	100
Bangladesh	1	40	40	100
Brazil	1	16	16	100
China	1	17	17	100
Ivory Coast	1	99	99	100
Mexico	1	20	20	100
Philippines	3	224	224	100
Vietnam	1	31	31	100
Indonesia	4	156	151	97
Vanuatu	1	79	71	90
Papua New Guinea	2	57	51	89
Sri Lanka	1	78	65	83
Fiji	1	11	9	82
Thailand	2	124	97	78
India	1	212	115	54
Solomon Islands	1	21	11	52
Malaysia	2	89	18	20
Jamaica	1	60	4	7
Ghana	1	16	0	0
Pakistan	1	32	0	0
Tonga	1	7	0	0
Western Samoa	1	9	0	0
Total	**30**	**1402**	**1043**	**Average 74**

A total of 1043 accessions in the CGRD are localized by longitude and latitude. Because of duplicates, these 1043 accessions refer to only 710 distinct cultivars or population names. Only 579 collecting sites have a unique combination of latitude and longitude, to the level of minutes.

Currently, the CGRD database gives only the geographical localization of the factual female parent, i.e. the location of the palms where the seednuts of the accession have been collected. Many accessions have been moved from one research institute to another; others are rejuvenations of the original population within the same institute. In these two situations, as the female parent is located in a research institute, the geographic coordinates of the institute is given in the CGRD as the ‘collection site’. There is no direct information regarding the collecting site of the original sample of each accession.

Let us take a practical example. A researcher wants to know the real origin of the accession 'NCDP-D9'. This accession is a Tacunan Green Dwarf (originating from the Philippines) but planted in Tanzania in 1989:

1) Looking at the passport data entered in Tanzania, the researcher will see that the accession 'NCDP-D9' came from 'Station Marc Delorme', a research centre in Côte d'Ivoire. For the accession 'NCDP-D9' the latitude and longitude given as collection site indeed refers to the research station in Côte d'Ivoire, the place where the seednuts were collected. Unfortunately, both fields 'male parent' accession number and 'female parent' accession number have yet to be entered in Tanzania's collection record. Therefore, the researcher would not know the parental accession of 'NCDP-D9'.
2) However, looking at all the data from Côte d'Ivoire, a researcher will see that there is only one accession of 'Tacunan Green Dwarf' in Côte d'Ivoire: it is the accession 'SMD NVP3' planted in 1982. Therefore, she/he will conclude that 'NCDP-D9' is the progeny of 'SMD NVP3'. Looking further at the passport data of Côte d'Ivoire germplasm collection, she/he will see that the accession 'SMD NVP3' came from the Davao Research Centre in the Philippines. However, no accession from the Davao Research Centre is yet registered in the CGRD database.
3) Nevertheless, if the researcher is clever and persistent, she/he will check all coconut accessions available in the Philippines. She/he will finally find that the original accession of Tacunan Green Dwarf is also available at the Zamboanga Research Centre, as accession 'ZRC PD1' planted in 1977. Based on CGRD, the original collection site of 'ZRC PD1', and therefore 'NCDP-D9' is the village of Tacunan, Davao, 007°04'N, 125°36'E.

This search process will take a researcher at least 15 minutes, and it will require some luck for complete success. Just one piece of information missing in the whole line and, it becomes difficult to make the links. Another option available in CGRD consists in searching directly all the accessions of 'Tacunan Green Dwarf' registered worldwide, but even this does not solve the problem. Both descriptors list and dedicated software have been conceived for managing complete information, and therefore become inefficient if information is incomplete. Data regarding the collection site of the original sample should be recorded in the passport data of each accession.

Nevertheless, the status of georeferencing of coconut accessions (Table 1) compares favourably with other crops. In the CGRD, 74% of the accessions have latitude and longitude information. As there are 1402 accessions but only 710 distinct cultivars/population names, it can be said that more than 80% of the coconut cultivars of the world's germplasm banks are geo-referenced. As comparison, only 9% of the accessions of six major genebanks of the United State Department of Agriculture have coordinates, although 50% have a locality description (Greene and Hart 1996). Therefore, in the case of the coconut palm, a large amount of geographical information exists. The challenge is to improve its reliability, to make it more easily available, and to use it to improve coconut genetic resources conservation.

Mapping collection sites

Mapping of the locations where accessions were collected was done using GIS tools. This may be defined as a database management system which can simultaneously handle spatial data i.e., maps, or the 'where'– and related, logically-attached, non-spatial, attribute data, and the labels and descriptions of the different areas within a map, or the 'what' (Guarino *et al*. 2002). It is a tool for managing information of any kind according to where it is located (Treweek 1999). The main elements of a GIS are as follows (Guarino 1995; Guarino *et al*. 1999):

- Data input, verification and editing
- Data storage, retrieval and management
- Data manipulation and analysis
- Output

The first mapping was done using the Map module of the Corel Quattro-Pro Software (Bourdeix *et al.* 1999). The data obtained were checked to detect and correct abnormal localizations. As many island countries were involved, a very convenient test was to detect errors such as accessions which appear to have been collected in the open sea ('sea coconuts'). Sometimes the commercial maps were inaccurate and had to be changed. Lists of errors and corrections were exchanged a number of times with most of the countries in order to reach an acceptable level of precision.

This work has not yet been systematically conducted on the entire database. The number of coconut accessions registered in the CGRD database increased from 665 in 1994-1995 to more than 1400 as of 2003. No checking of geographical coordinates was done after 1999 at the database level. There is thus a need to continue this work more efficiently.

The International Plant Genetic Resources Institute (IPGRI) and the International Potato Center (CIP) collaborated and developed specialized GIS software called DIVA-GIS that could be downloaded free from Internet at http://diva-gis.org/. DIVA-GIS is dedicated to the analysis of genebank and herbarium databases to elucidate genetic, ecological and geographic patterns in the distribution of crops and wild species.

The maps in Figures 1, 2 and 3 have been made using the 579 locations where coconut accessions have been collected. Climatic information from various sources can be used in conjunction with these georeferenced accessions to determine the zone of cultivation of the coconut palm. A DIVA-GIS module uses the Food and Agricultural Organization (FAO) Ecocrop database of crop climatic and other environmental requirements together with world climatic surfaces to predict the level of crop adaptation, particularly coconut, over geographic areas. By superimposing the theoretical coconut growing area and the location of collecting sites, it is possible to visualize covered geographical regions. Some areas remain clearly under-represented in the national and international coconut

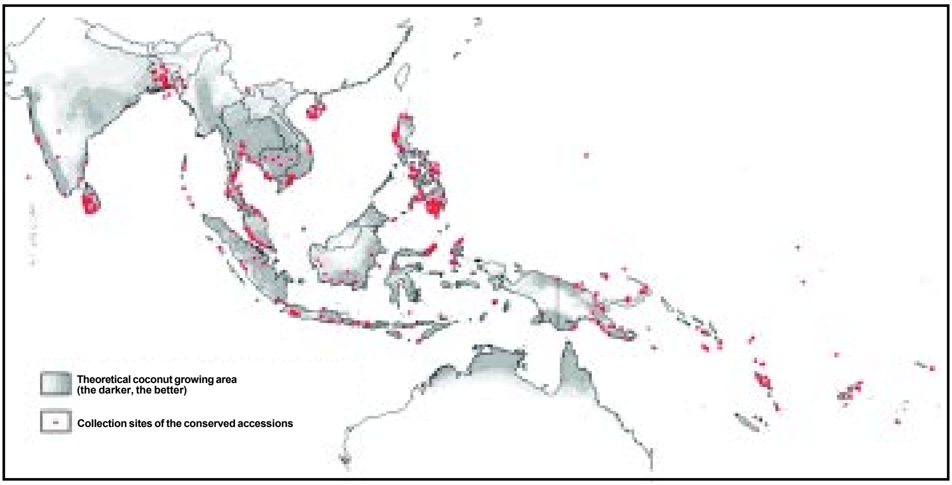

Figure 1. Mapping of the locations where coconut accessions were collected in Asia and the Pacific regions.

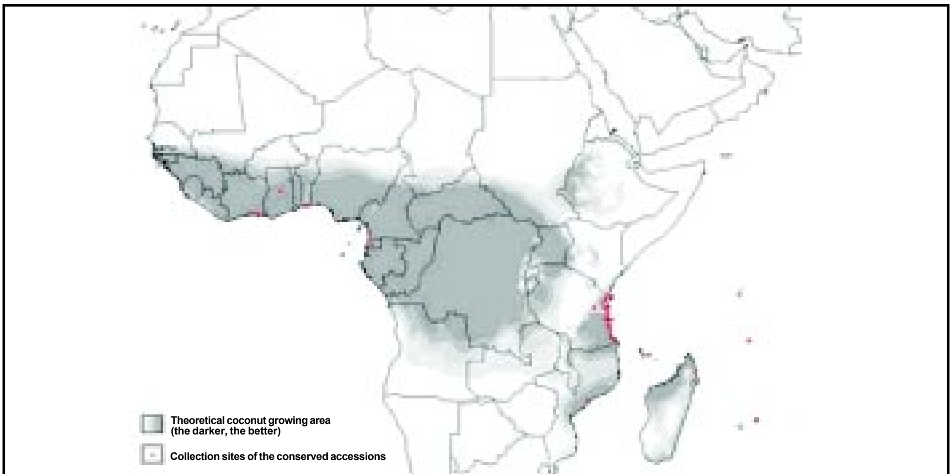

Figure 2. Mapping of the locations where coconut accessions were collected in Africa and Indian Ocean regions.

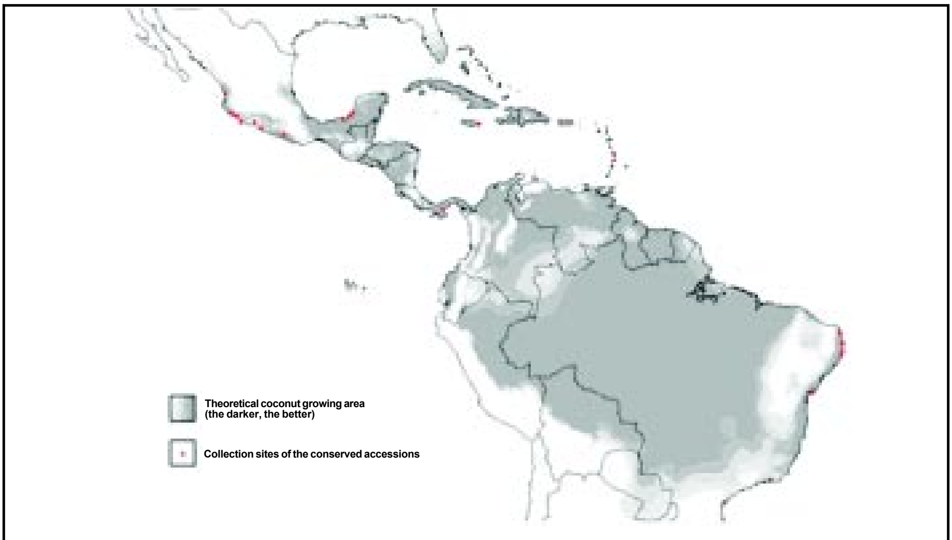

Figure 3. Mapping of the locations where coconut accessions were collected in America.

germplasm centres. These are areas where coconut palm can grow, but where there are no accession points recorded. For details of this analysis see Chapter 2 on 'Status, gaps and strategy in coconut germplasm collecting'.

DIVA-GIS can also be used to check the coordinates of the collection sites in relation to an administrative boundaries database. In effect, this would automate the data-checking process (including locating 'sea coconuts') which used to be done manually. It would therefore be useful in the future to create an interface between CGRD and DIVA-GIS. This would require a module allowing the export of data from the CGRD in a format easily readable by DIVA-GIS.

Mapping morphometric characteristics

Further analytical functions implemented in DIVA-GIS include mapping the distribution of specific traits and mapping of richness and diversity. Genetic diversity mapping usually begins by dividing the target area (or strata within the target area, e.g. climate zones) into a number of smaller zones, for each of which a measure of diversity can be calculated (Guarino *et al*. 2002). Different geometric, political or socioeconomic spatial units have been used, but ideally, areas of equal shape and size (to reduce the effect of the area on diversity measures) should be employed, for example square grid cells (Nabhan 1991; Ferguson *et al*. 1998).

One of the important parameters describing the quality of the coconut fruit is the Q factor. The Q factor can be defined as the weight of husk divided by the weight of the fruit without free water (coconut water inside the nut). The quantity of free water is quite variable according to environmental factors (such as rainfall) and the degree of maturity of the fruit. This is the reason why the Q factor is calculated without taking into account the free water. The larger the Q factor, the higher the proportion of husk in the fruit.

Normally, to get a good estimate of fruit composition, a sample of two fruits is analyzed six times a year over four years on each palm, and this must be done on 30 palms to characterize an accession. In CGRD version 5.0, only 32% of the accessions have data for fruit component analysis. But in practice, the data are even less complete. It can be estimated that at least 20% of the fruit component data available in CGRD 5.0 were derived from the analysis of a single fruit sample harvested at one point. This again reinforces the importance of having complete data in order to carry out an analysis that can be really useful in germplasm conservation, management and use. In any case, all the available georeferenced accessions with fruit analysis data were used to carry out some spatial analyses. The first results obtained were not convincing, because they included both Tall and Dwarf cultivars, which have distinct fruit characteristics.

Nevertheless, there was a clear geographical pattern, based on the geographical distribution of mean values of Q factor, for Tall cultivars (Figure 4). Accessions originating from India and Africa show a higher Q value than accessions from Southeast Asia and the Pacific region.

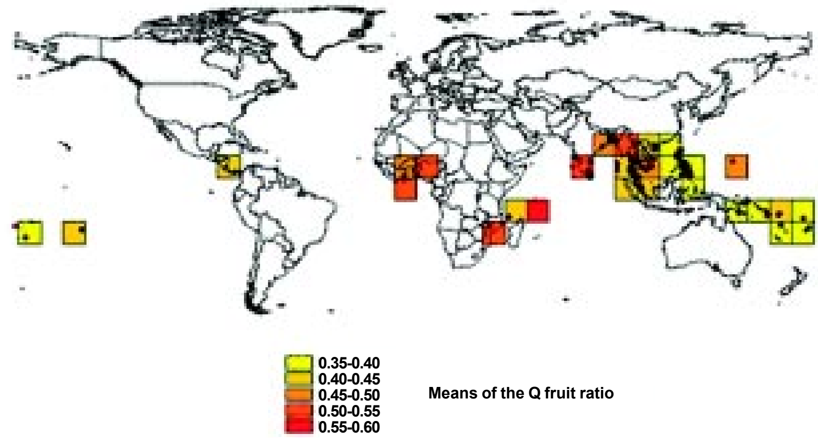

Figure 4. Geographical distribution of mean values of the Q factor for Tall cultivars

Mapping molecular markers

New functionality in version 2 of the DIVA-GIS software includes options of mapping based on molecular markers (DNA) data that are illustrated here by an example. Figure 5 presents the geographical repartition of allele 128 of locus *CnCir A3* in the Tall coconut varieties (see Lebrun *et al.*, Chapter 4). Allele 128 is one of the four alleles whose presence at a significant frequency is characteristic of Indo-Atlantic coconuts. Similar (but not identical) pictures could be obtained with any of these markers. Allele 128 is found at a high frequency in an area extending from the Indian sub-continent to the Atlantic coast of America. It is rare or absent in the eastern part of Southeast Asia, in the South Pacific and on the Pacific coasts of America.

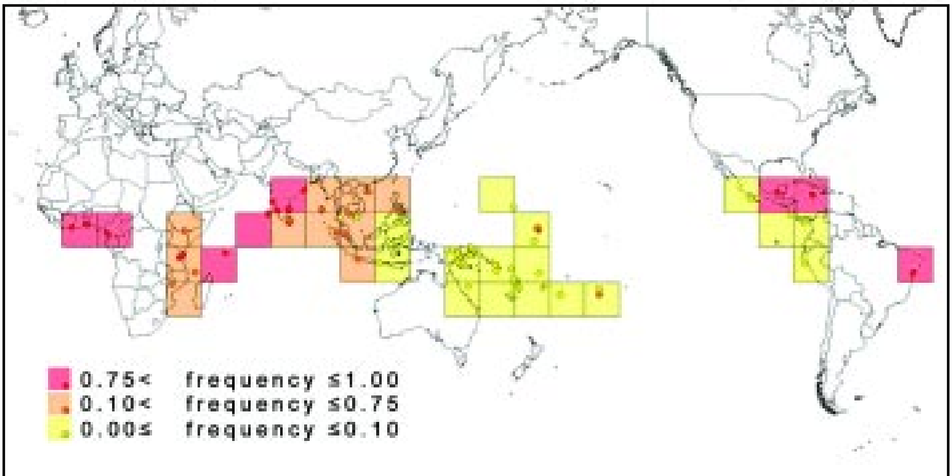

Figure 5. Geographical distribution of the frequency range of the allele 128 of locus cnCir A3 in the Tall coconut varieties.

The average frequency is based on the samples studied, which do not necessarily reflect the relative abundance of the cultivars. Nevertheless, if we consider the picture in more detail, the intermediate frequencies observed in East Africa result most probably from the introduction of coconuts from South Asia by Austronesian navigators, whose language is still spoken in Madagascar. There is also a transition zone in the western part of Southeast Asia, demonstrating some genetic exchange with South Asia. This may have involved floating, but the activity of Arab merchants who have crossed it for several centuries is probably the cause of most of the exchanges across the Indian Ocean.

The apparently medium frequency of this allele in Sri Lanka is actually an artefact in the Sri Lanka Tall, by far the most dominant cultivar of this country. The allele 128 frequency is 0.82, but other cultivars, with a round nut were also sampled, which could be the result of hybridization of local coconuts with planting material imported at different periods from Southeast Asia.

Finally, three cultivars with allele 128 frequencies between 0.10 and 0.16 are found in the Pacific Ocean. Considering the three other characteristic (marker) alleles, they are probably not related to the Indo-Atlantic group. The presence of allele 128 at a low frequency in this area is probably a case of homoplasy (i.e., the fact that similar traits – here, fragments with the same length – appear independently by mutation in different genetic groups). Homoplasy is not infrequent in microsatellites.

Mapping for collecting genetic diversity

The genetic diversity mapping described in this Chapter concerns mainly coconut palms that are already in genebanks and their characteristics, such as fruit composition and molecular marker profiles. Another possible field of investigation could be to study coconut populations *in situ* and to map their diversity before the collecting of seednuts or embryos. According to Pernes (1984), the best germplasm collecting programmes are carried out in two stages, with a first exploration and preliminary survey used as a basis for studies that will permit better planning of the second, more systematic campaign. Such a two-step programme was done in Mexico (Zizumbo Villarreal *et al*. 1993) where fruit analyses were made first at 47 localities along the Atlantic and Pacific coasts and in the narrowest part of the country (the States of Oaxaca and Veracruz). Collecting was then carried out in only 19 localities, 90% on the Pacific coast, where the greatest fruit variability was found.

However, most budget appropriations seldom permit such organized programme. It is also necessary to underline the great sensitivity of the coconut to environmental variations. The phenotype of a palm at a certain moment is usually not representative of its genetic value. There is much variation linked to heterogeneity of the field, for example in soil fertility or water availability. The growth of the coconut palm is controlled by various rhythms, depending on internal and external factors. Although it may produce continuously, yields are often irregularly distributed over the year. Biannual cycles are superimposed on this variation. These phenomena are rather frequent in young palms or following droughts (Bourdeix *et al*. 1994). For a proper evaluation, vegetative and yield characteristics of a sufficient number of palms should be measured over a period of several years. Nucé de Lamothe and Wuidart (1982) have emphasized that it is difficult to conduct such a study outside a research station. However, it will be possible to collect leaf samples from surveys, to analyze their DNA and then to sample the field origin where genetic diversity is greatest. Up to now, we have no example of such a strategy, but it may happen in the near future (see related articles in Chapter 2).

Conclusion

Recent developments in GIS technology for mapping genetic diversity is expected to contribute significantly to identify and fill the gaps in coconut collections, enhance the effectiveness of collecting, better manage them in field genebanks, effectively select parents from geographically distinct regions and expand coconut production through site-genotype matching. Figure 6 provides an analogous map of the number of accessions registered in the germplasm banks of the COGENT member countries.

An additional effort is needed to make coconut descriptors list and related software better adapted to management of incomplete data. The new version of DIVA-GIS software (Version 4.0) can be downloaded free from the internet (http://www.diva-gis.org), and is easy to learn and use, and is tailor-made for genetic resources applications. Country-level GIS databases can also be downloaded from this site and these databases can be used together with the genetic resources databases that are being mapped and analyzed. These are files with data on administrative boundaries, country boundaries, and first and second level administrative subdivisions for most countries. For all countries, grids are available for altitude, land cover and population density. DIVA-GIS can be used to check existing coordinates and carry out analyses of characterization and evaluation data. Specific software devoted to the management of genetic resources, such as CGRD for coconut, could be improved by allowing easy exporting of data to DIVA-GIS.

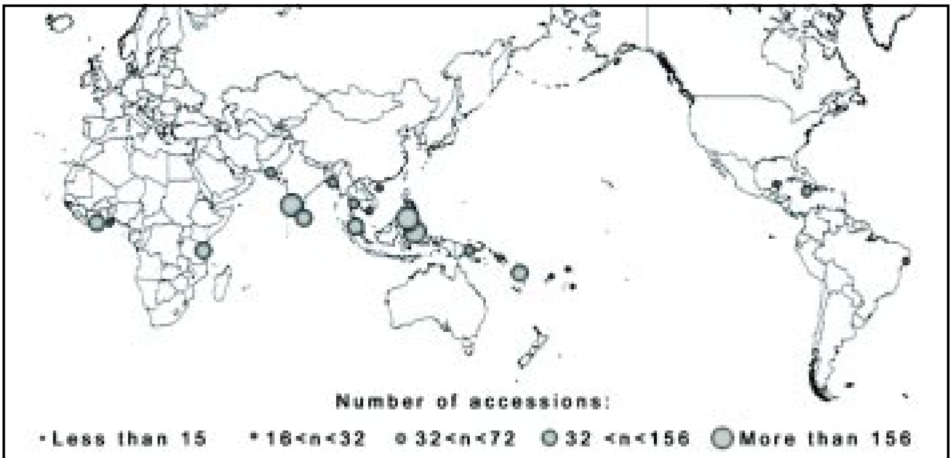

Figure 6. Geographical distribution of the coconut accessions conserved in COGENT germplasm banks

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Status, gaps and strategy in coconut germplasm collecting

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Introduction

The International Coconut Genetic Resources Network (COGENT) Steering Committee decided to promote germplasm collecting in areas at risk of genetic erosion at its first meeting in Singapore in 1992. This was expected to fill the gaps in national collections, developing (and refining) both morphometric and molecular markers techniques for efficiently locating diversity and transferring efficient and practical techniques for collecting.

Phase 1 of the COGENT project 'Coconut Genetic Resources Network in Asia and the Pacific Region' was completed in July 1997. A regional network consisting of 13 countries was established to foster the conservation and utilization of coconut genetic resources. In December 1998, the Asian Development Bank (ADB) approved Phase 2 of the project. Its objective was to expand the network to 20 countries, to further promote coconut collecting and sustainable conservation, and to strengthen human resources. During 1997-2000, many coconut accessions were collected and planted in field genebanks in all the network member countries. The main objective of this chapter is to review and assess the strategies used in collecting coconut germplasm and make suggestions for future work.

Status of coconut germplasm collecting

As noted earlier, many coconut accessions have been collected and conserved (see Chapter 5 for more details). Access to information about this coconut germplasm is much better than it was ten years ago. COGENT network members are regularly updating passport information and characterization data of accessions in the Coconut Genetic Resources Database (CGRD). If a new coconut accession is now collected somewhere, there is a reasonably high probability that passport data will be available to the whole network through the CGRD, within one or two years.

In the CGRD Version 5.1 (April 2002), the total number of accession was 1416, of which 216 had no registered accession size (number of true-to-type living palms in the field). This means either that all palms of these accessions are dead or that data on them is missing. Information on dead accessions is kept in the database because it remains essential to researchers. Some general statistics on coconut collections are given below:

- 1186 accessions have a size of one or more palms
- There are only 620 distinct names (of cultivars or populations)
- 74% of accessions are of the Tall type
- 25% are of the Dwarf type, and the remaining 1% are intermediate forms
- 140 000 is the total number of 'living' palms
- The average number of palms per accession is 118 and per cultivar, 225
- About 30% of accessions have already been duplicated in several genebanks or rejuvenated

Another very important piece of information is the 'Date of Last Inventory/Counting' of each accession. It is the most recent date on which the number of living palms was checked. An examination of this field shows the following disturbing trend for the 1193 accessions, which have an accession size of at least one palm:

- For 36%, the Date of Last Inventory (DLI) remains unknown
- For 6%, DLI is during the past three years (2000-2002)
- For 47%, DLI is between 1996 and 1999
- For 11%, DLI is prior to 1995

During the period 1996-2001, visits were conducted to many countries to train and assist researchers to input data into CGRD (Bourdeix 1996; 1997a; 1997b; 1998; Bourdeix *et al*. 1999; Baudouin 2001). Although this improved data management, there is a strong need for continued efforts in this regard. In particular, checking and entering DLI should be done at least once a year. In addition, among the 1416 accessions, 120 (of which 16 were from Jamaica, 32 from Pakistan and 29 for Bangladesh, and 43 from various other countries) do not have any registered 'acquisition date'.

The oldest accession registered in CGRD is a Samoan Tall planted in 1912 in the Solomon Islands. Levers Plantations began there around 1905. Coconut research is said to have begun in India in 1916 and a varietal collection was started there in 1921 (Harries 1978). Twenty-three accessions were planted in India between 1934 and 1946 and are registered in CGRD database. An accession from Mapanget, Indonesia is dated 1927. The Coconut Research Scheme was established in Ceylon

– now Sri Lanka - in 1929. The depressed copra market of the 1930s impeded research, and a varietal survey that began in 1939 was terminated after only a few months (W.V.D. Pieris, personal communication, cited by Harries 1978) and the oldest accessions are dated 1954. In Africa, the Marc Delorme Research Centre began its activities in Côte d'Ivoire in the fifties (Nuce de Lamothe and Wuidart 1979).

Parham (1960) carried out one of the first scientific surveys intended to collect coconut palms and breadfruit trees in the Pacific. As a result, some coconut varieties with very large fruits, such as the Markham Valley Tall, were introduced to various genebanks throughout the world. Whitehead (1966) conducted a survey in the Pacific searching for varieties tolerant to the Lethal Yellowing disease of Jamaica. An indirect result of this work was to inspire Harries (1978) to develop his theory of evolution and dissemination of the coconut palm. Vanuatu began its germplasm planting in 1963 and the Philippines in 1976.

An examination of the CGRD also reveals that from 1912 to date, there have been only 11 years during which 50 or more coconut accessions were collected per year. Five of these 11 years were between 1992 and 1999, (i.e. during the early days of the COGENT). The other years in which at least 50 accessions were collected, were 1981 and from 1983-87. Around 30% of the registered accessions were planted after the COGENT was established (1992 and later). However, no accession acquired between 2000 and 2003 is registered in the CGRD database at the time of writing this paper. This suggests a significant reduction in collecting activities in the past three years.

Gaps in coconut germplasm collecting

The foregoing historical survey has established the fact that a substantial number of coconut accessions are being conserved in genebanks around the world. However, there may still be compelling reasons for further collecting. Additional collecting may be justified if:

1. Diversity is still missing or has been lost from existing *ex situ* collections;
2. Diversity is in imminent danger of disappearing from farmers' fields; and
3. Diversity is needed for immediate use and is not available from existing collections.

Related palm species

The palm family (Palmae or Arecaceae) counts about 2800 species scattered among 190 genera. The Cocoeae tribe contains 27 genera and nearly 600 species, including several economically important plants such as *Cocos nucifera* L. (coconut), *Elaeis guineensis* (African oil palm), *Attalea* *cohune* (babacu) and *Bactris gasipaes* (peach palm). Morphologically, the Cocoeae tribe is characterized by having the synapomorphy of presence of three or more pores or 'eyes' on the endocarp (Gunn 2002). It comprises of six sub-tribes, among which the Butiinae includes the *Cocos* genus and seven American genera (plus a recently discovered genus from Madagascar, *Voaniola*). Since most of the related genera are American in origin, in the past it was speculated that coconut also originated in Americas (Cook 1901). In recent classifications, *Cocos nucifera* L. is considered as the only species of the genus. It is generally considered that it cannot be crossed with any other species. However, as far as we know, no published report of such an attempt to date. There is thus an opportunity for research in this field, checking for such possibilities, as resistance to lethal yellowing in allied palms closest to coconut may be a revealing exercise. If nothing else, it would establish that the coconut is indeed a botanical and genetic 'outlier'.

Geographical gap-filling

Most often, gap-filling collecting focuses on uncovered geographical regions, which may be quite extensive, e.g. a whole country. Figures 1, 2 and 3 in the earlier article 'Mapping of coconut genetic diversity' can be used to visualize inadequately covered geographical regions by superimposing the theoretical coconut growing area and the location of collection sites. The zones coloured in grey, which are climatically suitable for coconut, do not seem to have coconut occurring in them, however, this needs to be confirmed by ground truthing (i.e. checking in the field).

It must be noted, however, that some areas may be better represented than they might look in these maps. For instance, India is probably better surveyed than the map implies, but Indian researchers have not yet inputted all the geographic coordinates of their national accessions. A collecting mission was conducted in Madagascar in 1999 by Indian researchers, but collecting information remains incomplete.

Some other areas are probably of low coconut diversity. For instance, for historical reasons, there is probably a low probability of finding unique diversity in African countries such as Congo, Democratic Republic of Congo, Angola, Ethiopia and Sudan. The same could be true in South America – in the central part of Brazil, and the parts of Peru and Bolivia east of the Andes. Nevertheless, all these zones have never been surveyed for coconut, and exploration would be justified.

Some areas remain clearly under-represented in national and international genebanks, which are listed below, in a subjective ranking of priority:

1. The west coast of South and Central America (except Mexico and Panama, which have already been surveyed). Germplasm

collecting is presently being conducted in Guatemala. These studies are essential, considering the problem of the Lethal Yellowing Disease and the history of coconut in this region;

2. A large part of Micronesia, including the Caroline and Mariannas Islands;
3. The eastern part of Polynesia, including the Tuamotu and the Marquesas Islands and Hawaii;
4. Irian Jaya and the Moluccas archipelago;
5. The tropical coasts of Australia and the Cocos/Keelings Islands, where putative wild coconut occurs (Williams 1990; Leach *et al.* 2003);
6. Madagascar. Seafarers from Southeast Asia reached this island probably around the sixth century AD and settled there. Molecular biology studies show that they probably introduced coconut seednuts with them, and new diversity developed thereafter; and
7. Other more localized areas like Somalia, Myanmar, Laos and Sarawak in Malaysia.

Some of the areas that are suggested here (such as Micronesia, eastern Polynesia, and the Cocos/Keelings Islands) represent only a very small part of the coconut world, in terms of cultivated area and economic value. However, these areas could prove to be extremely important for coconut diversity. Pacific Islanders, especially Polynesians, have been involved in coconut cultivation and transportation for a very long time. Coconut diversity is more endangered in these areas, precisely due to its comparatively low economic importance and due to the possible effects of global warming and other human activities.

It is interesting to note that the Arab traveller Ibn Batutta reported the presence of coconut in Yemen in 14th century. Climate is considerably drier at present than in antiquity (and probably than at the time of Ibn Batutta), and Yemen is not reported as a producing country. However, contact with local botanists could reveal the presence of a few remnants of this historically interesting population.

Targeted surveys and under-represented phenotypes

The various existing *ex situ* collections are still not fully representative of the germplasm available in farmers' fields, especially with regard to the diversity of climate under which coconut is grown. Occasionally, specific environmental conditions may be targeted. For example, high-altitude or cold-tolerant varieties remain under-represented in coconut collections. Finally, missing genotypes are sometimes targeted, e.g. named varieties of known appearance, which are not found in collections.

Most of the old surveys, such as those of Parham (1960) or Nuce de Lamothe and Wuidart (1979), intentionally focused on varieties with large, thin-husked fruits. Many farmers indeed prefer big round nuts. However, the use of the coconut husk is making a comeback, and it seems very important for the future to further safeguard and study the thick husked varieties.

Coconut from India and Africa has, on average, higher husk content than most of the coconut from Asia and the Pacific. In the Pacific, 'Niu Kafa' types are an exception. However, there are references from everywhere, including Southeast Asia, describing a few coconut varieties with a high percentage of husk. In 1978, Harries developed a theory about coconut evolution, dissemination and classification of the coconut. He used the name Niu Kafa to describe a putative wild coconut palm with a large husk. "First came the natural evolution and dissemination by floating of a variety with large, long, angular, thick husked and slow germinating fruits. From this thick-husk type, selection under cultivation produced a spherical fruited variety, not necessarily larger but with increased endosperm, reduced husk thickness, earlier germination and disease resistance" (Harries 1978). However, according to Foale (1987), islanders also selected other palms bearing fruits that contained long fibres to make strong twine and ropes for use in the construction of both buildings and boats. Consequently, the huge fruits presently known as Niu Afa in Samoa, Niu Kafa in Tonga and Magi Magi in Fiji are no longer wild coconuts; they are varieties highly selected by the Polynesians for the utilization of husk. This is particularly clear in Samoa, where the variety seems to occur in its purest form, and where the palms are located near houses and are all of a homogeneous green colour.

An important theoretical question that arises is whether there is a link between the Indo-African Coconut group and the Pacific and Asiatic cultivars with high husk content. Molecular techniques may help to resolve such a question. However, so far only a very few samples of the Niu Kafa type have reached laboratories in good order. Only one typical sample could be analyzed, and it appears that it is not closely related to the Indo-Atlantic coconuts. At least 20 to 30 more samples of thick-husked varieties originating from different parts in Asia, the Pacific and Oceania should be collected and DNA-analyzed. These varieties could be of Niu Kafa types, but they may also give smaller fruits of quite different shapes. Some varieties from the Tuvalu archipelago have high husk content but with a shape that, although elongated, is very different from those of Niu Kafa (Labouisse and Bourdeix 2003). It is important to collect different putative 'wild' coconut types and analyze them using molecular markers. Such a study may enhance our knowledge about dissemination and help in refining collecting strategies and even the design of coconut breeding programmes.

Another endangered special phenotype is a class of coconut varieties described as 'Sweet Husk'. The husk of young fruits of this type is soft and sweet and can be chewed like sugarcane. When over-mature, the fruits can be husked easily. Fruits of these varieties are generally eaten by children, flying foxes and rats before nuts mature. It is almost impossible to collect them in a classical survey, as no seed is usually available. Local people are no longer interested in them as in the past as consuming them due to changes in social norms. For example, Tiara Mataora, from the Cook Islands said "I like it but do not want somebody to see me chewing sweet husk, because these people will think I am a poor man". A special effort to collect and study these types must be made. Such special variants could be useful for making high value products for the tender nut market.

Two important collecting programmes were known to focus on particular traits: drought adaptation in Sri Lanka (Liyanage *et al*. 1988), and selection for Lethal Yellowing Disease (LYD) tolerance in Tanzania (Schuiling *et al*. 1992). It seems that these two programmes have not really been successful. The accessions from areas in Tanzania with high LYD pressure continue to die from the disease during the next generation. Accessions collected in Sri Lanka from both dry and wet zones were compared under dry conditions, but no significantly different reactions were noted.

Other interesting types will probably emerge from the results of the farmer participatory approach (see related section below).

Losses from existing *ex situ* collections

The life span of coconut accessions is sometimes shorter in germplasm conservation centres than in farmers' fields. Some example will illustrate this. Indonesian accessions registered in the CGRD are conserved at four different sites: Mapanget (Manado City), Pakuwon, Bone-Bone and Sikijang, Selakau (West Kalimantan), Makariki (Molluccas) and Marihat (North Sumatra) (Rognon and Batugal 1998). However, Indonesian researchers in Manado informed us that these conservation sites are no longer in use. The remaining accessions in Marihat are said to be original populations and to date, these have not been duplicated anywhere else and thus become important for future rejuvenation and planting in current genebanks.

In CGRD Version 5 (2002), 55 Indonesian accessions out of 156 do not have any data for the accession size field (number of living palms) and the date of the last inventory/counting. Some of these accessions, such as the 1995 planting in Manado and those conserved at the Bone-

Bone Station, appeared to have been destroyed and later was no longer considered as a coconut germplasm centre. According to Indonesian researchers, the 41 accessions (1682 palms planted between 1984 and 1988) are considered lost. At Sikijang, at least 25 accessions, with 100 palms each, were planted in 1998 and 1999. Because of various factors, including fire, in January 2001 (i.e. only 3 years later) 77% of these palms were either dead or in a poor condition. Due to the change of status of Sikijang station, it is assumed that the 30 accessions at that station were mostly lost. However, as some palms remained, they have not been removed from the inventory. Indonesian germplasm now stands at 170 accessions (including some new ones), of which 61 can be considered as lost. Therefore, the real number of living accessions for Indonesia cannot be more than 109, with 4976 palms (on average, only 46 palms per accession). At least 65 accessions from Indonesia are now lost and should be re-collected (after having found a way to safely conserve them for the future).

In Papua New Guinea, demonstration plots of various cultivars were planted during the early 1930s at the Bubia Lowland Agricultural Experimental Station. In 1964, it was decided to plant a new trial at Kapogere Agricultural Station in the Central District, Papua. The scope of the trial was broadened to include at least nine foreign introductions: New Hebrides, Solomon Islands, Malaysia, Rennell Island, Singapore, Ceylon-Random, Ceylon-Selected, Maldives and Fiji Talls. The status of these accessions remains unknown. They are not registered in CGRD and they were not transferred to the international collection in Madang. The accessions collected in the past and planted in old, possibly now neglected, field genebanks should be safeguarded.

In Thailand, it seems that some old accessions were cut without being rejuvenated in order to plant oil palm experiments. The sustainability of germplasm banks seems better in Côte d'Ivoire, India, the Philippines and Sri Lanka.

Targeted exchanges between germplasm conservation centres can help in duplicating accessions in different genebanks for safety and in promoting the sustainability of coconut genetic resources conservation. Exchange of germplasm immediately after a collecting mission is also advantageous as many freshly collected embryos would be available and could be exchanged safely. The exchange of coconut germplasm among coconut-producing countries remains very limited. For example, from 1995 to 1999, only one coconut variety was exchanged between the Philippines and Vietnam. In contrast, more than 80% of the foreign cultivars existing in Brazil, Indonesia, Philippines, Tanzania, Thailand, Sri Lanka and Vietnam came from the Marc Delorme Research Centre in Africa in the past.

India is an exception, with a strong collecting programme abroad. But only a few palms remain from the survey conducted by Indian researchers in Madagascar. Five accessions were collected in 1997 from a single location in Sambava province. Many plantlets died before reaching the field planting stage. These may have to be re-collected to have a representative population of these accessions.

More than 3000 coconut embryos were collected from Tuvalu, Cook Islands, Marshall Islands and Kiribati and sent to the Secretariat of the Pacific Community's (SPC) Regional Germplasm Centre (RGC) in Suva, Fiji. Unfortunately, almost all these embryos died during the *in vitro* culture and/or the transfer to the International Coconut Genebank (ICG) in Papua New Guinea. The reasons for these losses were the high rate of contamination and low rate of rooting. Some of these accessions need to be collected again.

An FAO report by Pieris (1966) indicated that the concern for collecting exotic germplasm was high in the early 60s, as about 30 countries reported seed or pollen exchange. This period contributed indeed to the richness of present genebanks. However, many of the cultivars are no longer reported in the receiving country. For example, the Philippines received planting material from 14 countries primarily for resistance trials against Cadang-Cadang. Apparently, nothing is left from this introduction and some of these cultivars had to be re-sampled about 20 years later.

Genetic erosion

To understand on a smaller scale the mechanisms that build diversity and the factors that influence the evolution of coconut types, a study was undertaken in Vanuatu, a remote archipelago in the South Pacific (Caillon 2003). There were 60 variants named based on a particular aspect describing distinct character from the rest of the population (Labouisse and Caillon 2001). Of these 60 variants, 45% may not be selected but are still recognized, 20% are chosen for their social importance (e.g. a coconut brought by a local mythical hero), 15% to make copra, 13.3% for their nutritional qualities and 6.7% for non-food uses (e.g. containers, ropes). In a remote village of a northern island (Vanua Lava), where 30 variants are found, only 5% of all the coconuts planted by 25 farmers are named (Caillon, pers. com.). Coconuts selected for their domestic and social interest are the least numerous (7.4% and 8.5% of the planted variants, respectively) whereas 46.9% are planted for food purposes. The most striking example concerns the variant with a large proportion of husk traditionally used to make ropes. These specific coconut types are currently ignored as other types of ropes have become more prominent. At the same time, the importance of copra for cash has increased. As a result, truly 'high husked' variant can only be found on old plantations dating from the time when farmers still used coconut ropes. This exemplifies genetic erosion due to changes in farmers' preferences.

The number of named variants in a field depends on a farmer's willingness to select and plant variants with characteristics other than high copra, in order to respond to other uses for food, shelter or social needs. Generally, planting material for new plantation comes from farmer's own garden or from a nearby plantation. However, the most remarkable variants come from other plantations, sometimes distant, where the farmers might have seen while helping other villagers/farmers making copra and brought a few seednuts back. However, that level of diversity also varies greatly depending on the degree of knowledge of a farmer about his/her own coconuts. Thus, young plantations planted by the current generation owner in which immature fruits are accessible and where copra is frequently made will be the richest ones in terms of genetic diversity. Consequently, the reduction of named variants at a village scale is due to the combination of cultural erosion through the loss of traditional uses and through the younger generations' loss of ability to identify variants. Such loss caused by social process could further be demonstrated more clearly by molecular techniques to assess real genetic erosion even if variants are not readily identified but are still growing around and are able to exchange genes through allogamy. Such an approach is currently underway.

Changes in land use patterns, urban migration, industrialization and replacement with other species (such as oil palm) or with introduced and/or improved varieties (hybrids) are contributing greatly to the loss of coconut diversity. Natural calamities (cyclones, drought, diseases such as cadang-cadang and lethal yellowing) as well as human induced ones (pollution, war, etc.) are also agents of genetic erosion.

Strategy in coconut germplasm collecting: Towards a diversity of approaches

No single approach is likely to be effective to collect and conserve the full range of variation within a target gene pool and making it available to breeders and other users, and coconut is no exception. Collecting germplasm for *ex situ* conservation should thus be regarded as simply one of the components in a comprehensive strategy for conservation of the target gene pool.

Until recently, coconut surveys were faced with two constraints linked to the biology of the plant. The first is the large size of the fruits; a sample of a hundred fruits often weighs more than 150 kg. The volume of the fruits considerably restricts the number of samples that can be transported, or leads to a reduction of the effectiveness of the samples. Another constraint is the nature of the seed. The coconut, with recalcitrant seeds (Roberts *et al*. 1984), looses germination capacity rapidly. Most cultivars have no dormancy period; the seeds start to sprout 1-3 months after reaching maturity. Moreover, the coconut seed is relatively sensitive to cold. Due to these characteristics, numerous samples of coconut varieties have been lost partly or totally for various reasons: survey conditions did not allow for sufficient sampling or ships transporting the fruits passed through zones that were too cold, or duration of transport and customs clearance exceeded the survival time of the seeds. For these reasons, in all research stations some coconut accessions can be found that are represented by numbers that are too low to constitute a good population for conservation, though originally large number of nuts might have been sampled. The application of new technologies makes it possible to get around some of these problems (see Engelmann, Chapter 2). However, much care needs to be exercised to avoid what happened recently in the Pacific.

Bourdeix *et al.* (1999) described case studies that were conducted in 14 countries involved in coconut germplasm surveys during the 1994-1999. These detailed studies cannot be reproduced *in extenso* here but some of the most general conclusions and thoughts are discussed in the next section.

The Coarse Grid Strategy

In 1997, a manual on coconut breeding research techniques (STANTECH) was published and distributed to coconut-producing countries (Santos *et al*. 1996). This manual describes the bases of the recommended collecting method in its Chapter 3 on 'Germplasm exploration and collecting' and Chapter 10 'Generalized sampling strategy'. The Coarse Grid Sampling strategy described here has been applied systematically to cover the coconut areas in the Philippines (Santos 1987) and Malaysia (Jamadon 1987). The basic elements of this process is described below by Guarino *et al*. (1998).

As noted earlier, the COGENT member countries have collected significant amount of coconut genetic diversity during 1993-2000, with support from ADB. A research team from the French Agricultural Research Centre for International Development (CIRAD) was mandated to review and assess the effectiveness of the collecting strategies followed in the first phase of this project. This study noted that only one country, the Philippines, made use of grid sampling technique. No country used 'coconut importance value' suggested in the collecting strategy. It must

The Coarse Grid Strategy

How can a national, regional or international coconut research programme assess the relative importance of the different reasons for collecting? It will clearly need some basic information on its mandate region:

- Where is the crop growing, in relation to agro ecological zones of the region?
- How much genetic variation is already present in genebanks?
- What are the main agents of genetic erosion and where are they most threatening?
- Who are the principal users and what are their needs?

The sources of this information will include agricultural censuses and atlases, the databases of genebanks, local extension agents and their records and coconut breeders. Based on this information, it should be possible to identify (and prioritise among) areas of the following types within the mandate region:

1. Under-represented areas. These can be identified by mapping passport data of existing collections, and include areas where collecting has been inadequate or has not occurred at all.
2. Complementary areas. These are areas, which are genetically, or environmentally different from areas from which collecting has already taken place, based on passport and characterization data.
3. Environmentally or genetically diverse areas. In previously uncollected or under-collected areas, it is advantageous to collect over wide range of agroecological conditions because genetic diversity is partially correlated with environmental diversity. Preliminary characterization and evaluation (including genetic diversity studies) of conserved material may have identified areas, which are particularly diverse genetically.
4. Areas with target genetic material. This may be inferred from environmental conditions, known from previous characterization and evaluation work and/or revealed by local knowledge.
5. Threatened areas. These may be identified by local people, repeat visits, etc.

Based on the points derived from the brief survey of patterns of genetic diversity in coconut, the following basic elements of a coconut collecting strategy are proposed:

Choosing the sites

1. Divide the coconut-growing region in 40x40 km grids. This should be done separately and independently for each sub-regional grouping (stratified sampling). In general, collecting in the SE Asian region should be more intensive, so smaller grid sizes could be used.
2. Superimpose the location of the different types of areas listed above on

the grid. This can be done using a GIS. Calculate a 'coconut collecting importance value' (CCIV) for each grid square based on the presence and priority value of each type of area in the grid area.

3. If possible, carry out a preliminary exploratory visit to 2-3 sites per grid square and collect morphological information to complement characterization information from germplasm already conserved. Use this information to further refine the CCIV.
4. Collect germplasm systematically at a minimum of two sites in all grid squares. If the material is of the same ecotype and/or environmental conditions are similar, leave a minimum of 15 km between sites.
5. Collect more intensively (up to six sites) in grid squares that have a higher CCIV.

however be noted that much of the collecting in Phase I was over in 1997, while the strategy was developed in 1998. Most of the surveys were conducted by following, more or less precisely, administrative divisions such as regions, subregion and districts. Major constraints noted for the implementation of the collecting strategy were the time and capacity to build geographical grids that need well documented information such as climate, soil and population data. CIRAD team then recommended that the International Plant Genetic Resources Institute (IPGRI) should prepare, for national researchers, computerized maps with standardized geographical grids already documented with general information and national researchers to focus on gathering plant-specific information. However, it is not possible for IPGRI to undertake such country specific activity and training national partners to develop their capacity to make the grids, etc., will be more appropriate. This is also appropriate in the light of other developments in the area of climate and other data that are now available on the web (see below).

Independent of the report by the CIRAD team, CIP (International Potato Center) and the IPGRI have collaborated since 1999 in developing the software DIVA-GIS. This software is a Geographical Information System tailor-made for genetic resources applications. The DIVA-GIS may be downloaded free from the Internet at http://diva-gis.org/. The question of availability of collecting grids remains open and is currently being discussed with the DIVA-GIS developers. In the future, it will be useful to standardize the use of these grids at global level - not only for the coconut palm, but also for all crops. It is suggested here to use a grid of 20′ of latitude x 20′ of longitude instead of 40 km x 40 km squares. Such a grid is easier to draw using a GIS or even a commercial map, by interpolating available parallels and meridians. At the equator, the side of cell is about 1852 km x 20= 37 km. As latitude increases, the N-S sides remain constant, while the E-W sides decrease progressively. However, it is still close to 35 km at latitude of 20°. Thus, at least at subtropical latitudes, it is almost equivalent to using grids measured in km or in minutes. Discussion on this proposal is in progress.

Germplasm collecting programmes are best carried out in two stages. The first phase consist of exploration and preliminary survey to collect information on sites and material that occurs in those sites which will permit better planning of the second phase. The second phase is the more systematic collecting mission. Following the geographic grid approach, the first step will be to gather considerable data *in situ* (such as fruit component analysis, evidence of erosion, etc.) and samples for DNA testing. The data gathered during the exploration phase will then be analyzed, including using GIS tools. The next step will consist of returning to a limited number of specific sites that are expected to have high, unique, new, useful or threatened coconut genetic diversity, based on the information gathered in phase I, in order to harvest seednuts and bring them back to the genebank(s). The information from areas where no collecting takes place will have value for ground-truthing the theoretical distribution of coconut cultivation (see section on geographical gaps in this article), as well as for determining future on-farm conservation sites and monitoring genetic erosion. Up to now, there is no example of such a strategy using both *in situ* field characterization and DNA analysis as a decision-making process. However, with the microsatellite tool kit ready for use, this is expected to occur in the near future.

Although the two-phase collecting as described above would be ideal, for practical reasons including financial and time constraints, it may be impossible to visit the same place twice as suggested. An alternative method would be to collect directly seednuts and/or the embryos, and leaflet samples, at the same time, along with *in situ* characterization data such as fruit components. Back at the germplasm centre, DNA from the leaflets or from nuts germinated in the nursery should be analyzed to decide on which samples to include in the genebank as 'accessions' i.e., all the populations sampled may not be planted in the genebank. The objective is to use the diversity and other observation data to enable planting only the accessions representing particularly high, unique, new, useful or threatened genetic diversity. This is important as the maintenance of large number accessions in field genebanks by national organizations is very difficult and very expensive. Therefore, genebanks with a minimum number of accessions that capture maximum useful genetic diversity are needed.

It must be noted, however, that although some samples may not be included in the genebank, the data (including the collecting data) on all samples would be very useful to maintain for mapping purposes.

The farmer participatory approach

There is a growing recognition that the effective conservation of biodiversity will depend on the long-term participation and understanding of local communities. Participatory Rural Appraisal (PRA) comprises a set of techniques aimed at shared learning between local people and outsiders (Baker 2000). Collectors require training in specialized participatory methodologies such as PRA, in particular the use of visual methods (sketches, ranking, diagramming, and cognitive mapping). Important considerations include how to choose informants, the best time for consultations, whether individual interviews should be complemented with group discussions, and ethical issues such as informed consent and anonymity (Ramanatha Rao *et al*. 1998; Eyzaguirre and Batugal 1999).

An example from India may reveal a quite surprising aspect of the PRA method, however. This example was found in a research report distributed during the 1998 COGENT Steering Committee meeting held in Kuala Lumpur, Malaysia. The report states that in India, farmer's participatory survey was conducted in eight sites representing the three major agro-climatic regions of Kerala. At each site, the interaction was based on a semi-structured questionnaire and lasted some 6-8 hours. The popularity of various coconut varieties was evaluated, including: Tall types, Dwarf x Tall hybrids such as COD x WCT (Chowgat Orange Dwarf x West Coast Tall), and the 'Natural Cross Progeny of the Chowgat Orange Dwarf' (NCD). According to participants, many farmers produced NCDs by sowing their own Dwarfs nuts and selecting off-types based on their brown petiole colour for their own use as well as for sale within the locality.

In all the eight study sites, the participants favoured off-types of COD (NCDs) in place of TxD and DxT hybrids for cultivation. However, these NCDs are nothing more than natural DxT hybrids! The brown colour of NCDs petiole indicates that the Red Dwarf, as mother palm, is naturally crossed with Green or Brown Coconut palms, i.e. the West Coast Tall coconut available all around in farmers' fields as male parents. So, the two cultivars compared – Hybrids and NCDs – are in fact the same genetic material. This point was not underlined by the researchers in charge of the PRA survey and analysis. Anyway, it demonstrates that the farmers indeed practice a certain amount of crop improvement and are able to generate their own hybrid seednuts. But the only difference between NCDs and Dwarf x Tall hybrids is that research centres release 'hybrids', while

NCDs are selected by farmers in their own gardens. That may explain the farmers' preference.

Application of PRA methods to obtaining crucial information on the origin and extent of the genetic diversity that is being collected would be most useful in areas where people maintain the closest relationship with their coconut palms. Surveys conducted in archipelagos such as Cook Islands and Tuvalu indicate that germplasm diversity and knowledge seem to be higher in the most isolated islands (Labouisse and Bourdeix 2003; Caillon 2003). This type of information helps in the collecting process, in particular:

Locating and accessing target areas and material. Locating target germplasm means being in the right place at the right time. Specialist local knowledge is often the best guide not only to where a particular variety may be found, but also to the optimal timing of collecting.

Deciding what to collect and how. When material with particular characteristics is being sought, indigenous knowledge can provide crucial clues.

Assessing the completeness of collecting. Local men and women know which varieties are grown in their village or district or are being sold in the local markets. A checklist compiled on the basis of such information can act as a guide to collecting in a given area, providing a benchmark for comprehensive sampling of the available diversity.

Understanding the origin and distribution of diversity. Landraces are at least partly shaped by what may be referred to as the informal plant breeding and seed production and supply systems. Thus, understanding the diversity within a crop in an area (which is crucial to developing a conservation strategy) means understanding the practices of the people who grow it.

Assessing the reasons for, extent and danger of genetic erosion. Oral testimony is often the only source of information on change in the extent of cultivation of a crop, and in the cultural practices being used. Older farmers will sometimes remember the names and attributes of landraces, which they no longer grow, and which may have entirely disappeared from their area.

Documenting and using the collection. Local knowledge should form an important part of the documentation of germplasm samples. Farmers are aware of the many characteristics and properties of varieties.

Documenting such local knowledge of the appearance, properties and adaptations of germplasm should be seen as an integral part of the characterization and evaluation process, and as such as an important way of facilitating and accelerating the use of conserved germplasm.

Conclusion

Though it is now well recognized that a significant amount of coconut diversity has been collected and conserved in several coconut research organizations, especially since the establishment of COGENT, their representation and availability of associated data are still incomplete. There is still substantial uncollected indigenous germplasm, and some of it is under threat of genetic erosion. The most important reason for the continued occurrence of coconut diversity is that farmers have interest in and possess knowledge about their coconut varieties. However, along with the diversity, such knowledge is rapidly eroding in some areas as so-called modernization and globalisation reach into even the most remote parts of the world. Researchers will have to focus on breeding and germplasm utilization to benefit from the investment made in collecting and conserving.

Emphasis should be placed on the use of molecular techniques and morphological characterization to rationalize large collections in order to reduce the actual number of cultivars in the germplasm centres from around 350 to 150-200, so that the genebanks are more manageable, both in terms of financial and human resources and scientific backstopping. Then additional collecting, using these new screening techniques, should allow adding 150-200 more priority accessions. The use of Geographical Information Systems tools will facilitate the task of the collectors.

Some elements were discussed regarding the effectiveness of targeted collecting, as compared to comprehensive grid sampling and farmer participatory methods. Use of the concept of CCIV could further help in identifying the priority accessions to be included in genebank collections and training to implement collecting strategy and the use of GIS tools is considered important to enhance the efficiency of collecting. Thick-husked varieties from Asia/Pacific and sweet husk varieties are two endangered phenotypes that should be targeted. Surveys that are more systematic should be conducted in areas that have not been covered during previous collecting programmes. Some important accessions that have been lost in collections should also be re-collected. Farmer’s participatory methods should be applied in communities where people know a great deal about every coconut palm in their gardens (such as very isolated islands) to document the knowledge and practices farmers use to maintain coconut diversity in their fields.

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In vitro collecting of coconut germplasm

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Introduction

In vitro collecting (i.e., the utilization of *in vitro* culture techniques for collecting plant germplasm) offers the plant collector an additional option for solving various problems which can be encountered during collecting expeditions. The application of *in vitro* collecting is particularly useful for the two main categories of problem crops (i.e., vegetatively propagated species and species with recalcitrant seeds) (Withers 2002). *In vitro* collecting protocols have now been developed for a number of different species (Pence *et al*. 2002).

In the case of coconut, seeds are bulky and heavy, making them costly to transport. They are also highly recalcitrant (Chin and Roberts 1980). These characteristics limit the amount of material that can be collected and restrict the geographic range of collecting missions. These limitations may have serious consequences for genetic resources conservation, since it is recognized that a large amount of the untapped genetic diversity in coconut is located in remote areas, such as atoll islands. The key to solving these problems, however, lies in recognizing that only the embryo is needed to propagate a coconut palm. Various efficient *in vitro* culture protocols are available which allow the production of whole plantlets from coconut zygotic embryos inoculated *in vitro* (Batugal and Engelmann 1998; Engelmann *et al*. 2002).

Status of work

Research on the adaptation of *in vitro* culture techniques to collecting coconut embryos was initiated 15 years ago under the aegis of the IBPGR (International Board for Plant Genetic Resources, the predecessor of International Plant Genetic Resources Institute -IPGRI), with the aim of facilitating not only the collecting but also the international exchange of coconut germplasm. In addition to the advantages offered by this technique for collecting genetic resources, *in vitro* collecting would also avoid the transmission of important coconut diseases, which do not pass through the embryo. This is particularly important with the expected increase in international exchange of coconut germplasm linked with the establishment of the multi-site International Coconut Genebank

(Ramanatha Rao and Batugal 1998). Various *in vitro* collecting techniques have been developed by different teams, thereby demonstrating not only the feasibility of collecting isolated embryos, but also the great flexibility that can be exercised within the basic concept (Engelmann 2002).

The *in vitro* culture of coconut embryos has been adapted by several researchers in collecting coconut germplasm from the field. The techniques basically include the following sequence of operations:

- Dehusking and cracking open the nut;
- Extracting a plug of endosperm containing the embryo by using a cork borer;
- Dissecting the embryo from the endosperm; and
- Inoculating the embryo into culture.

The methods developed differ in the degree to which attempts are made to reproduce laboratory conditions in the field, the amount of *in vitro* work actually performed in the field, and, therefore, the point at which sterilization is carried out. Their utilization requires varying levels of technical expertise, and the method selected will depend on the circumstances of the collecting mission and on the tissue culture expertise available among the collecting team.

The simplest methods, which do not require specific expertise at the collecting site, are one of the two methods developed in Côte d'Ivoire (Assy-Bah *et al*. 1987) and that established in the Philippines (Rillo and Paloma 1991; Rillo 1995). In the first protocol developed by Assy-Bah *et al*. (1987), after disinfection, the plugs of endosperm containing the embryos are placed in a solution of KCl (16.2 g l^{-1}), then brought back to the laboratory where they are redisinfected and inoculated *in vitro* under the laminar flow (see Protocol 1 below). In the protocol developed in the Philippines, plugs of endosperm containing the embryos are extracted in the field, brought to a simple isolation room close to the collecting site, disinfected with alcohol and commercial bleach, placed in sterile plastic bags with sterile, moist cotton and transported in cold storage. Upon arrival in the laboratory, subsequent manipulations are carried out aseptically, under the laminar flow hood. The cylinders of endosperm are resterilized with commercial bleach, and the embryos are extracted and inoculated *in vitro* for germination and growth. This protocol is used routinely in the Philippines in the framework of programmes for mass production of Makapuno embryos (Rillo 1999).

Another protocol, which has been established by Australian researchers, requires some tissue culture expertise because embryos have to be extracted from the albumen immediately after their collection, but allows transport time of up to six weeks (Ashburner *et al.* 1995, 1996;

Samosir *et al.* 1999). Plugs of endosperm are collected in the field and transported to an improvised laboratory close to the collecting site, where the embryos are extracted from the albumen, sterilized with commercial bleach, and inoculated into 2 ml sterile plastic cryotubes containing sterile water. Manipulations after arrival in the laboratory are performed aseptically under the laminar flow hood. The embryos are resterilized and inoculated *in vitro* for germination and growth

In the other protocols (i.e. the second protocol developed in Côte d'Ivoire, see below) (Assy-Bah *et al.* 1987) and those established by Sossou *et al.* (1987) and Karun *et al.* (1993), *in vitro* inoculation of the embryos is performed directly at the collecting site, thus requiring the relevant expertise to be available within the collecting team. The field equipment requirements are greater than in the protocols described above, but even these methods range in complexity. The technique of Sossou *et al.* (1987) attempts to simulate laboratory facilities and methods in the field using an inflatable glove box. The protocols established by Assy-Bah *et al.* (1987) and Karun *et al.* (1993), however, accept the limitations of working in the field and present a lower-technology approach. Endosperm plugs are extracted from the nuts and disinfected with commercial bleach. The embryos are then dissected and inoculated inside a wooden or plexiglass box (to protect from airborne contaminants) and transferred into sterile culture tubes. With the protocol developed by the research team from India, embryos are either directly inoculated on growth medium or kept for 2-4 months in sterile water (Karun *et al.* 1996). This protocol has been used successfully by Indian researchers to collect several thousand embryos from remote Indian Ocean islands (Karun *et al.* 1998; 2002). All these protocols give good results, with contamination percentages below 10% of the inoculated embryos.

Detailed description of the in vitro *collecting protocols developed by Assy-Bah* et al. *(1987)*

Assy-Bah *et al.* (1987) developed two coconut embryo *in vitro* collecting protocols - one consisting of storing the disinfected embryos in a KCl solution until they are brought back to the laboratory, where they are redisinfected and inoculated *in vitro* under sterile conditions, and the other including *in vitro* inoculation of the embryos in the field. Details of the protocols are as follows:

Protocol 1 (inoculation of embryos in the laboratory)

Preliminary operations are performed in the open air, on a folding table that has been washed and disinfected with a bleaching solution.

1. Select and dehusk mature nuts.
2. Break nuts open with a clean hammer.

3. Use a cork borer to remove a cylinder of solid endosperm containing the embryo, and use forceps to transfer the cylinder to a jar containing 500 ml of commercial bleach. Disinfect all instruments with commercial bleach and sterilize in the flame of the gas burner.
4. Immerse batches of 25 cylinders in commercial bleach for 20 minutes.
5. Immediately after disinfecting, transfer endosperm cylinders without rinsing in individual 30 ml containers containing 15 ml KCl solution (16.2 g/l).

The following steps are performed in the laboratory, under the laminar airflow cabinet.

1. Remove endosperm cylinders from the KCl solution and immerse in batches of 25 cylinders in commercial bleach for 20 minutes.
2. Place one cylinder in a sterile Petri dish and dissect out the embryo using forceps and a scalpel. Flame dissecting tools before manipulating a new embryo to reduce the risk of cross-contamination.
3. Rinse the embryo once in sterile water (using one flask per embryo to reduce the risk of cross-contamination) and transfer it to solid medium in a culture tube.
4. Seal the tube with cling film and place it on a rack for culture in the growth room.

Protocol 2 (inoculation of embryos in the field)
Steps 1-5 are the same as in Protocol 1 above.

The following steps are performed inside a wooden box, which provides some protection from external contaminants. The inside walls of the box are disinfected with bleach.

1. Place one cylinder in a sterile Petri dish and dissect out the embryo using forceps and a scalpel. Flame dissecting tools before manipulating a new embryo to reduce the risk of cross-contamination.
2. Rinse the embryo once in sterile water (using one flask per embryo to reduce the risk of cross-contamination) and transfer it to solid medium in a culture tube.
3. Seal the tube with cling film and place it on a rack for transport to the laboratory.

Using Protocol 2, contamination was around 10%, while it was only around 5% with Protocol 1. No differences were noted in germination and development between embryos treated following Protocols 1 and 2. Embryos could be stored for up to 14 days in the KCl solution without any effect on their further development. After direct inoculation in the field (following Protocol 2), embryos could be kept in semi-solid medium under non-controlled environmental conditions for two months before being grown in the culture room of a laboratory (Engelmann and Assy-Bah 1992). These results were confirmed recently by N'Nan (personal communication) following a series of *in vitro* collecting experiments performed in Côte d'Ivoire in 2001. *In vitro* collecting has been used routinely to collect and send over 20000 embryos from Côte d'Ivoire to France over the last two years.

In vitro *culture of embryos*

After inoculation *in vitro*, embryos have to be germinated and grown into weanable (acclimatized and hardened) plantlets. Research towards the development of *in vitro* culture protocols has been performed over the last 30 years by various research teams worldwide. An assessment of the available protocols, carried out during the IPGRI/COGENT-funded International Coconut Embryo Culture and Acclimatization Workshop held in the Philippines in 1997, revealed a large discrepancy in the performance of these *in vitro* culture protocols, with 14 to 55% of the inoculated embryos giving rise to plantlets growing *in vivo* (Engelmann 1998). The main bottleneck was the low efficiency of *in vitro* embryo germination and plantlet development. The protocols developed also differed in the culture conditions, composition and sequence of media employed and the stage of plantlets selected for weaning. Also, these protocols had been tested with a limited number of coconut varieties. In this workshop, which was participated by seven countries, the embryo culture techniques of country participants were compared and good features were adopted to develop an upgraded protocol to be further tested. The results of this workshop were published to guide embryo culture researchers (Batugal and Engelmann 1998). Another IPGRI/COGENT-coordinated international project, funded by the UK Department for International Development (DFID), was thus implemented to address two main objectives: (1) to improve the maturation and germination of embryos, and their development into plantlets; and (2) to determine and select the most efficient *in vitro* culture protocol and to test it with a large number of varieties (Batugal and Engelmann 1998). At the end of this project, the success of coconut embryo *in vitro* culture was significantly improved, with 31 to 81% of inoculated embryos developing into plantlets *in vivo* (Engelmann and Batugal 2002). A large diversity of coconut germplasm was employed since the tissue culture protocols have been tested with over 20 varieties. These experiments also revealed a very strong genotypic effect in response to *in vitro* culture. No optimal protocol was identified due to the high variability of the responses obtained in the different laboratories involved in the project. However, the 'hybrid protocol' proposed by one laboratory, which combines the most efficient steps of the four protocols tested, seems to hold good promises for further improving the performances of coconut embryo *in vitro* culture.

Zygotic embryos have also been employed as starting material for large-scale propagation of coconut genotypes through somatic embryogenesis (Verdeil *et al.* 1999). However, the reactivity of coconut tissues to *in vitro* manipulation is very low, and only few plantlets have been obtained from a limited number of coconut accessions. Additional research is therefore required before large-scale propagation of coconut through somatic embryogenesis can be undertaken.

Conclusion and prospects

The various examples of *in vitro* collecting protocols developed for coconut embryos range from extreme simplicity to a relatively high level of sophistication and illustrate the flexibility and adaptability of the basic concepts of the procedure. It is with coconut that the largest amount of research has been directed towards the establishment of *in vitro* collecting protocols because of the particular difficulties encountered with germplasm collecting and exchange for this species. *In vitro* collecting is currently used on a routine basis for coconut more than with any other species. The utilization of this technique is expected to increase with the establishment of COGENT's multi-site International Coconut Genebank, thus making coconut one of the best models for the application of *in vitro* collecting.

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Chapter 3

Germplasm conservation

Complementary conservation of coconuts

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Introduction

The main objective in any plant genetic resources (PGR) conservation programme is to maintain the highest possible level of genetic variability present across the genepool of a given species or crop both in its natural range and in a germplasm collection. The importance of conserving genetic variability or diversity is well recognized and such defense mechanisms need to be introduced into modern cultivars to make them sustainable (Martin *et al.* 1991; Chang 1994; Kannenberg and Falk 1995).

Countries that are signatories to the Convention of Biological Diversity endowed with significant amount of genetic and species diversity have a responsibility to the world at large to conserve them and make them available for use (Ramanatha Rao 1999). It is generally recognized that the two approaches of conservation, *ex situ* and *in situ*, are both important in the conservation and use of genetic diversity and should be regarded as complementary to each other (Maxted *et al*. 1997; Dulloo *et al.* 1998; Ramanatha Rao 1998; Engels and Wood 1999). The ultimate purpose of germplasm conservation is use and, consequently, any conservation strategy should include mechanisms that will ensure access to the germplasm by relevant stakeholders. Other important issues that must be addressed in a conservation strategy include issues related to policy and legal frameworks, documentation, socioeconomic aspects, infrastructure and networks. Since needs of users and technologies may change over time influencing the ways in which genetic resources are conserved and used in future and hence, should be taken into consideration when designing a conservation strategy. At an in house meeting organized by IPGRI in 2002, a complementary conservation strategy was defined as "the combination of different conservation actions, which together lead to an optimum sustainable use of genetic diversity existing in a target genepool, in the present and future."

A conservation strategy for coconut has been discussed in the past (Ramanatha Rao and Engelmann 2000; Ramanatha Rao *et al.* 1998) and the current status of the various conservation methods available for coconuts are described in this chapter**.** This paper discusses the constraints and advantages of these methods, the elements for a complementary conservation strategy and attempts to provide a framework from which a working strategy for conservation and use of coconut germplasm could be taken forward.

Methods for conserving coconut germplasm

As noted earlier, PGR are commonly conserved using *ex situ* or *in situ* approaches. *Ex situ* refers to their conservation outside their natural habitat in facilities such as in seed banks, field genebanks, *in vitro* collections, botanic gardens, with germplasm conserved in the form of plants, seeds, pollen, tissues, cells or DNA. In contrast, *in situ* conservation is conserving germplasm in the natural habitat where the target species is found, and in habitats such as farms and home gardens, where the species have developed their distinctive properties as a result of long-term selection by humans. The latter applies particularly to cultivated plants and their cultivars, landraces and weedy forms. Generally, there are three categories of *in situ* reserves: namely, those which maintain optimum conditions such as national parks and nature reserves, those which allow a range of economic activities by indigenous people as in extractive reserves national forests and Biosphere reserves, and a third category where local people act as custodians for the traditional varieties and selections contained in home gardens and farms (Damania 1996). Furthermore, IUCN (1994) classifies protected areas into six categories according to broad management objectives.

The previous chapters have described in detail the current status of conservation techniques coconut germplasm, an analysis of which could help in developing a complementary conservation strategy for coconuts. Table 1 examines the feasibility of different techniques, while Table 2 summarizes the constraints and advantages with regard to each of these methods. These two tables provide a comparative framework on which a complementary conservation strategy for coconuts could be based. It is important to emphasize that the information in Table 1 is based on our current knowledge, which could rapidly change in the near future, due to progress made in the development of the conservation methodologies. The biological characteristics of coconut and their compatibility with different options available are briefly discussed below. It is important to underline a fact at this point that when several options are combined to bring about a complementary strategy, we also bring along their advantages and disadvantages with the expectation that a synergistic effect is achieved.

The options for conserving coconuts are dependent on the biological characteristics of the whole plant and its component organs and tissues, as well as on the state of the technology as applied to coconuts. Coconut, a perennial palm, with exception of most of the Dwarfs, is an outbreeding species. It bears large size seeds that exhibit recalcitrant storage behaviour, rendering seed conservation not possible. Being a perennial crop, coconuts can be conserved *ex situ* as live plants in field genebanks or botanic gardens or *in situ* either on farm or in home gardens or on remote islands and atolls. Botanic gardens have limited capacity to conserve a broad range of genetic diversity due to the low number of plants that they can maintain. Field genebanks (attached to a coconut improvement organization) have been the preferred mode of coconut conservation to date, as they can be integrated into institutions and do not require highly technically skilled workers (Ramanatha Rao *et al.* 1998). However, field collections have some major disadvantages (Table 2). Coconuts are generally outbreeding, especially the Tall types, and requires wither spatial isolation or assisted-pollination. There are still some important research questions to be addressed in regard to collection management such as minimum number of trees needed to maintain representative genetic diversity, field plot techniques for characterization and evaluation and economics of collection maintenance. For details on field genebanks and the ICG, see related articles in this chapter.

On-farm conservation, where traditional crop cultivars or landraces and/or farming systems by farmers within traditional agricultural systems are maintained (Hodgkin *et al.* 1993; Jarvis 1999), has been gaining importance over the last decade. For coconuts, this method is particularly advantageous since most of the stands in South and Southeast Asia are in more or less intensively managed areas. For effective on-farm conservation, knowledge on the effects of farmers' practices on the extent and distribution of genetic diversity information on history of coconut cultivation and indigenous knowledge and actual genetic diversity measurements may be required. It is now possible to monitor and estimate genetic diversity using molecular markers for coconuts (Foale 1992; Ashburner and Rhode 1994; Lebrun *et al.* 1998; Mpunami *et al.* 1998; Perera *et al.* 1999). People's participation and cooperation among local people, researchers and conservationists and non-governmental organizations (NGOs), are essential ingredients of success for the sustainability of on-farm conservation efforts. Furthermore, any *in situ* conservation programme must benefit the local communities. Establishment of areas of intensive management or high yielding plantations would assist long-term sustainability of *in situ* conservation programmes. This is not to replace, but to bring a balance between high-yielding types for purely commercial purpose and landraces to satisfy all the personal and social needs of farmers. Such a balance is essential to promote conservation of landraces in the absence of any specific additional benefits to growers. This can attract commercial and private agencies to be partners in on-farm conservation efforts and can lead to much wanted linkages between public, community and private sectors in PGR conservation. For naturally occurring coconuts palms other forms of *in situ* conservation such as island reserves, biosphere reserves may have very important complementary value in conserving unique diversity as for example populations isolated on small uninhabited islands and atolls (Ramanatha Rao *et al.* 2000). For more detailed description of on-farm conservation, see related articles in this chapter.

Progress achieved in recent years in *in vitro* culture and cryopreservation as potential methods for conserving coconut germplasm augurs well for the future. Research on the development of such techniques has been performed with zygotic embryos, somatic embryos, pollen, apices and DNA material (Assy-Bah and Engelmann 1993). *In vitro* culture of zygotic embryos has been significantly improved and is now operational in an increasing number of laboratories (Engelmann *et al.* 2002). An efficient cryopreservation protocol has been developed for zygotic embryos (Assy-Bah and Engelmann 1992), which needs to be refined and tested on a range of ecotypes before becoming fully operational. Somatic embryos cannot be used for germplasm conservation since *in vitro* propagation of coconut using somatic embryogenesis is not yet functional. Cryopreservation of apices ('plumules') sampled from zygotic embryos is also possible (Hornung *et al*. 2001; Malaurie *et al.* 2002) but regeneration of whole plants from such explants is difficult. At the moment, plumules are of no use for germplasm conservation except possibly in case it would be proven that diseases (MLOs) can be transmitted through the embryo. DNA material can be cryopreserved easily and can be of great value in genetic diversity studies. However, regeneration into whole plants is problematic, if at all possible. For more details, see related articles in this chapter.

Conservation of coconut pollen is an additional option. Pollen can be dried and stored under vacuum for a short period of time (2-6 months) in a domestic deep freezer (Rognon and de Nucé de Lamothe 1978). Freeze-drying experiments showed no viability loss after 3 and 6 months (Whitehead 1966; Benard 1973) of storage at room temperature. Coconut pollen is highly tolerant to desiccation and preliminary experiments have demonstrated that coconut pollen could be successfully cryopreserved (Dr. Assy-Bah, unpublished results). Long-term storage of coconut pollen under cryopreservation would represent an important additional technique for genetic resources conservation, by allowing conservation of genes. However, additional research is still needed to further develop and refine a cryopreservation protocol.

Considerations for complementary conservation strategy

The knowledge of the biological characteristics of coconuts and how they can be conserved, as discussed above, is just one of the many elements for developing a sustainable complementary conservation strategy. This section discusses some other important elements, which need to be taken in to consideration.

Conservation objective

The most central element for developing a strategy is to define precisely what the objectives are. In this case, the general objective is to conserve and utilize maximum coconut genetic diversity. However, there would be other minor objectives for the establishment of a coconut genebank such as for immediate utilization, conservation for the long term, focusing on characterization and evaluation, etc. Strategy applied will also depend on what one would want to conserve, i.e. genes or genotypes. The strategy will be very different if the objective is to completely stop the evolutionary processes (e.g. cryopreservation) or in case the evolutionary processes need to be maintained (as in *in situ* conservation). Thus, if the promotion of conservation of landraces becomes the main objective, conservation on farm becomes the choice strategy for coconut, which also provides an opportunity for coconut to evolve under natural and farmer-imposed conditions. However, there is a need to accumulate more evidence on the role of farmer selection in a perennial crop like coconut. At the same time, with many farmers interested in increasing the productivity of coconut and income generation, breeding for higher yields and multiple uses becomes priority and hence *ex situ* conservation in field genebanks, which enhance the access to diversity by the coconut improvement scientists, becomes the choice for conserving and using maximum genetic diversity.

Genetic diversity

The major objective of any conservation effort, especially the one for long-term, is the conservation of maximum genetic diversity in a crop gene pool and this is true for coconut as well. Hence, the factors that contribute to the maximization of genetic diversity in a coconut collection (only infraspecific diversity in the case of coconut) have significant bearing on the balance of options chosen for inclusion in a conservation strategy. Coconut belongs to a monotypic genus and hence all its genetic diversity is in one species, i.e. *Cocos nucifera.* The diversity in coconut is mainly in the different ecotypes/landraces, i.e. conservation of genotypes and, consequently, using the field genebank allows conservation of most genetic diversity in the gene pool. Since very little information is available on the extent and distribution of coconut genetic diversity within and between populations and the genetics of useful traits, probability theory and random sampling (at times modified to include some level of bias for elite material, which is generally the norm for horticultural and perennial species) and larger populations are used to locate and conserve the desired level of genetic diversity. Under the ADB-funded project of COGENT, 28 countries have collected and conserved coconut germplasm in national field genebanks and a multi-site International Coconut Genebank (ICG) has been established, which makes the access to genetic diversity easy (see Batugal and Kanniah in this chapter). At the same time, COGENT also recognizes the limitations of the field genebanks. By using on-farm conservation, it is possible to conserve more diversity, especially that diversity which is directly useful to farmers. To do proper on-farm conservation, essential information on the extent and distribution of genetic diversity on farms is being generated. The limited observations to date have shown that very few farmers seem to pay any special attention to phenotypic and other differences in coconut types that they grow. Most often coconuts are just planted and little attention is paid later on. Hence, the so called indigenous knowledge on coconuts seems to be limited. Nevertheless, there are some who recognize this well, and hence should be targets for on-farm conservation efforts. Field genebanks require a substantial number of individual genotypes to be an effective conservation measure. Thus, extensive network of farm sites will be able to complement conservation of genetic diversity in coconut.

Stakeholders

Conservation of any genepool is not just a responsibility of an organization or individual. Several interested organizations and individuals are involved, including those who were responsible for the generation of the variability in the first place. Thus, in the case of coconut, the interests of small coconut farmers, organizations interested in their welfare and coconut research organizations/scientists and at the end the consumers, etc., need to be considered. For example, coconut farmers for whom coconut growing is a way of life and in some instances, growing the specific landraces or ecotypes, on-farm conservation takes precedence over the other approaches. This needs to be strengthened and complemented by other stakeholders who can play an important role in conserving that part of coconut diversity that might not be conserved on-farm due to reasons such as genetic erosion and utilization, using other complementary approaches such as conservation in field genebanks.

Infrastructure

The infrastructure needed and their availability determine the option to be chosen. Hence, the infrastructure needs for each of the option and their availability and resources required needs to be documented and analyzed. For example, the establishment of a field genebank for coconut genetic resources requires land, labour, good agronomy, facilities for exchange of germplasm, well-trained staff, etc. *In vitro* culture and cryopreservation would also require specific infrastructure and highly trained skilled staff. For on-farm conservation, identification of sites with high levels of genetic diversity, committed community-based organizations, staff skilled in working along with partners and farmers, access to conservation sites, monitoring mechanisms etc, have to be in place. Once such baseline information is available, then it should be possible to determine which approach will be used to particular part of coconut genetic diversity.

Socioeconomic aspects

The social considerations probably are more important in implementing on-farm conservation and less so while establishing *ex situ* conservation facilities. However, the economic aspect would be a key determinant in what methods are utilized. While planning for the former, several issues related to socioeconomics of coconut farming, indigenous knowledge, community participation, etc. have to be considered that make the on-farm conservation sustainable. Such considerations also make germplasm conserved on farm accessible for use by the farmers and communities as well as national agricultural research systems. Generally speaking, in the countries that are interested in conservation and use of coconut, the cultivation of coconut is not greatly threatened and will continue in the end. This consideration is important as establishing either *ex situ* or *in situ* conservation programmes are expensive and must be compatible with national objectives. Therefore, it is important to allow the increase of genetic diversity that is actually being planted by farmers to the extent possible. In this respect, a close cooperation between *in situ* and *ex situ* efforts is critically important.

Network

Any complementary conservation efforts for coconut at the national level have to be multidisciplinary and multi-stakeholder driven in order to conserve maximum diversity. Thus, an in-country network consisting of interested individuals, organizations (both public and non-governmental) and farmers is required. Similarly, developing a complementary conservation strategy at an international level requires coordination and collaboration among interested countries, as demonstrated by the International Coconut Genetic Resources Network (COGENT), as the genetic diversity that needs to be conserved is spread across borders.

COGENT has been able to complement the establishment of ICGs with efforts at community level that lead to on-farm conservation of coconut genetic resources. For example, the efforts to promote the cultivation of identified elite germplasm (landraces) from the genebank at sites where poverty reduction work are underway in Bangladesh, India, the Philippines, etc. This will ensure sustained conservation of landraces and at the same time benefit the poor coconut farmers.

Costs and risks

The options in any complementary conservation strategy need to be weighed against each other keeping in mind the relative costs, benefits and risks. With currently available methods, it has been generally agreed that the establishment of *ex situ* genebanks is relatively cost-effective and less risky (Pardey *et al.* 1999). However, using this one method, it would not be possible to conserve all the coconut genetic diversity that might be required in the future, especially when the number of accessions that could be maintained and managed in a field genebank is finite. Hence, a complementation by on-farm conservation of the material that would be difficult to bring to genebank becomes economical. *In situ* conservation option needs to be incorporated into the strategy. Such efforts also promote conservation through use. In addition, the analysis of the genetic diversity of coconut has shown that significant genetic diversity might exist in remote areas and atolls, collecting of which could be very expensive. One could argue that the germplasm located at these sites are relatively safe except for unfavourable climatic changes (e.g. sea level rise) which may be a risk and has to be considered. If resources are available, efforts should be made to collect and secure them in *ex situ* collections.

Policy/Legal issues

Without any doubt, for any conservation approach to be in place, much depends on the type of legal arrangements that can be put in place for transfer and access to genetic material and for sharing of benefits arising out of their use. In many countries, there may not be specific laws that prevent or promote the conservation of coconut genetic resources, but policies in a country could influence the importance accorded to such an effort. Thus, before venturing to establish a conservation strategy for coconut, it is important to check on the priority accorded to coconut at national level. For example, in most countries in the Asia Pacific, high priority is accorded to this crop and hence the efforts on its conservation and use are generally in line with the national policies. As noted earlier, conservation is mainly to make and keep the genetic resources accessible for use by users (researchers, farmers etc.). Hence the policies that promote the accessibility and transfer of material and 'information' are important for successful implementation of the different types of conservation. For example, if the national laws are very strict about collecting and using the material from farmers (as in the case of Philippines), conservation on farm may be the better option, especially for the new diversity. To establish a regional or international genebank, it is important that the partner countries policies do not hinder the exchange of coconut genetic resources, as exemplified by the agreement of participating countries in the establishment of the ICG (Ramanatha Rao and Batugal 1998).

Framework for complementary conservation strategy of coconut germplasm

It is evident from the above discussions that the options for conserving coconuts germplasm are rather limited (Table 1). The current practice, as already noted, is the use of field genebanks. On-farm conservation appears to have a great potential for such a perennial species as coconut. The perenniality, however, is also a constraint, as the information required for scientifically sound on-farm conservation would be limited. This is mainly because the information on farmers' practices in terms of selection and genetic diversity is limited since the crop's life might span over a couple of lifetimes of its growers. At present, *in vitro* collecting and *in vitro* culture of zygotic embryos that also facilitate movement of germplasm (phytosanitary aspects and cost) are fully operational. Cryopreservation, which ensures safe and cost-effective long-term storage, is expected to be operational soon after minor improvements to the existing protocol. The establishment of cryopreserved collections could be envisaged on a regional basis (e.g. one cryopreserved collection linked with each ICG site) or even on a global basis (one or two cryopreserved collections at sites agreed by COGENT partners) as a measure of long-term backup.

The balance between the different methods employed for coconuts would depend on many factors such as the intended use of the conserved germplasm, the method of maximizing the diversity of coconuts, the available infrastructure and human resources, space availability, accessibility and so on. Based on these elements and on the state of knowledge and the options available to date, a framework for complementary conservation strategy can now be developed. It is not envisaged here to develop a full strategy for coconut, but rather to propose a framework and the elements as how such a strategy could be developed at different levels: national, regional or international.

The framework can be seen as a series of steps (Figure 1). At each step information is gathered, specific actions taken and/or decision made.

The first step would be to organize the stakeholders into a network, as has happened in COGENT. This should be facilitated by a lead agency to enable its creation and be established with a steering committee composed of representatives of the various stakeholders. This would then be the decision making body to develop the strategy and take the decision on its content and implementation. The stakeholders would then be responsible to define objectives and sub-objectives according to its mandate. This would for example in the case of coconuts be to conserve and utilize the maximum genetic diversity in *Cocos nucifera*. A number of sub-objectives could also be elaborated such as the long-term conservation of coconut germplasm, conservation of specific ecotypes or characterization of germplasm, as mentioned earlier.

For each specific objective, the conservation options available should then be analyzed in terms of their feasibility and requirement in infrastructure, human resources, land, costs, accessibility and the risks involved. In relation to coconuts, we have seen that field genebanks and *on farm* conservation represent the best conservation methods but have certain limitations in the long term (Table 2). Other options like *in vitro* techniques and cryopreservation of zygotic embryos, for example, should be pursued in the future. The advantages and disadvantages of each of the possible options (Table 2) must be weighed against each other. This kind of analysis would provide the basis for taking decisions on which conservation options to be followed for given specific objectives.

The next important step in the process would be setting up the enabling environment to allow the conservation options to be implemented. This would involve, as discussed earlier, the policy issues in terms of legislation, germplasm exchange, benefit sharing and also most importantly the sources of funding. Once these are agreed upon and put into place, a strategic action plan can be developed and implemented (steps 6 and 7). For each step, the steering committee would examine the issues and take the relevant decisions and assign responsibilities to the various relevant players.

In conclusion, a complementary conservation strategy for coconuts requires a lot of efforts and commitment from many different stakeholders, who must work together with a common objective. A proper enabling environment, including *inter alia* policy, finances, incentives and good collaborative spirit, is crucial for its success.

Table 1. Comparison of conservation options for coconuts

	In situ **on farm /Home Gardens/natural habitats**	**Botanic Gardens (Living plants in gardens/ greenhouses)**	**'Conventional' Genebanks (seed banks, field genebanks)**	**Slow growth conditions (short-term)**	**Cryopreservation - liquid N (long-term)**
Mature plants	☑ Coconuts conserved on farm widely and in home gardens and natural stands exist on small isolated islands and atolls	☑ Occurs in botanic gardens but limited scope for conserving genetic diversity	☑ Field genebank most widely used conservation method so far. National and international coconut field genebanks exist	☒Not applicable	☒Not applicable
Seeds and zygotic embryos	☒ Not feasible- seeds are recalcitrant, no natural soil seed banks	☒Not feasible	☒ Seeds are recalcitrant and too large; seed conservation not feasible	☑Field collecting protocol established for zygotic embryos; *In vitro* culture functional	☑ Cryo-preservation protocol has been established for zygotic embryos; suitable for long term conservation
Somatic embryos	☒ Not applicable	☒ Not applicable	☒ Not applicable	☒ Mass propagation problematic; Not applicable	☒ not applicable
Pollen	☒ Not applicable	☒ Not applicable	☑ Possible, for short term conservation (2-6 months)	☒Not applicable	☑ Coconut pollen can be cryopreserved and could be suitable for long term conservation
Apices	☒ Not applicable	☒ Not applicable	☒ Not applicable	☒ Not applicable	☑ cryopreservation protocol established; relatively low survival and regeneration of plants very difficult
DNA	☒ Not applicable	☒ Not applicable	☑ Storage as DNA libraries exists – value not known	☒Not applicable	☑ Long-term storage possible (LN or –80°C freezer). Use of stored DNA questionable.

Table 2. Relative advantages and disadvantages of conservation methods for coconut

Method	Advantages	Disadvantages	Research needed
Field genebank	• Easy access for characterization, evaluation and use • Simple infrastructure needs • Does not require highly skilled manpower	• Space limitation compounded by need to maintain safe isolation distance between trees, especially for the Tall types that out cross frequently • Labour intensive; High risk in mislabelling • Vulnerability to biotic and abiotic factors • Exchange of germplasm • Participation with end users difficult • Legal issues as related to land ownership	• Minimum number of palms needed to maintain representative genetic diversity • Filed plot techniques for proper characterization and evaluation • Economics of coconut field genebank maintenance
In vitro collecting and culture of zygotic embryos	• Well established protocols • Facilitates germplasm exchange	• Only short-term storage • Relatively high infrastructure needs • High maintenance cost • Less accessible to users	• Testing of optimized *in vitro* culture protocol
Cryopreservation	• Feasible for long term secure storage • Easy to maintain, low costs • Protocol for coconut embryos has been developed • Not labour intensive	• Requires skilled labour • High initial investment cost for Infrastructure	• More work required to refine cryopreservation protocol
Pollen conservation	• Large number of samples can be maintained in small space • Easy to handle • Useful for crosses • Can be cryopreserved allowing long term storage	• Not yet feasible for long term • Only conserve part of diversity • Cannot be used to conserve specific genotypes	• Refinement on cryopreservation protocol • Desiccation tolerance
On-farm	• Dynamic conservation in relation to environmental changes • Participation of local communities and stakeholders made easier • Conserve a much larger genetic diversity overall • Highly suitable for coconuts • Difficult to exchange germplasm	• Vulnerable to natural and man-directed disasters, e.g. fire, cyclones, vandalism, change in land use, deforestation etc. • Materials not easily available for utilisation • Appropriate management regimes poorly understood • Require active supervision and monitoring • Genetic diversity scattered	• Little information on status of genetic diversity across coconut stands. • Systematic documentation of farmers knowledge is needed • Several issues related to socioeconomics of coconut farming, indigenous knowledge, community participation in relation to on-farm conservation • On farm conservation methodologies need further work • Ways and means to enhance benefits for promoting conservation on farm • Piloting *in situ* methods for locating, measuring and monitoring genetic diversity

Figure 1. Framework for developing a complementary conservation strategy

Step 1 Networking of stakeholders at national, regional or international, as the case may be

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Step 2 Definition of objectives and sub-objectives

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Step 3 Analysis of the feasibility of each option for each sub-objective in terms of infrastructure needs, costs, risks involved, etc.

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Step 4 Decision on conservation options for each objective/sub-objective

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Step 5 Setting up enabling environment – policy/legal issues, funding, etc

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Step 6 Elaboration of Strategic Action Plan by stakeholder/s

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Step 7 Implementation process

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Coconut field genebank

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Introduction

The two basic approaches to conservation of plant genetic resources (PGR) are termed *ex situ* and *in situ*. *Ex situ* approach involves conserving the genetic resources outside their original habitat in the form of seed, embryos, tissues or plants. Methods of *ex situ* conservation can include cold storage, *in vitro* storage or field genebanks, depending on the propagules used. In contrast, *in situ* conservation involves the maintenance of genetic diversity of a species or genepool in the habitat in which the diversity evolved. In the definition of the Convention on Biological Diversity (CBD), it includes the maintenance of diversity in farmers' fields and orchards, thus it includes the so-called on-farm conservation. It is now well recognised that for any given genepool, a number of different approaches and methods will be necessary for efficient and cost-effective conservation. Such a strategy is termed as complementary conservation strategy (Ehsan *et al*. 2003). However, with the current level of conservation options for coconut, field genebanks still play the major role in their conservation and use. It is presently the most feasible *ex situ* conservation method that can be used for coconut. This chapter attempts to look at the general nature of conservation of PGR in field genebank and looks specifically on how coconut fits into this context.

Field genebanks

Many important varieties of field and horticultural crops including coconuts are either difficult or impossible to conserve as seeds (i.e. no seeds are formed or if formed, the seeds are recalcitrant) or the species are vegetatively propagated. Conservation in field genebanks (FGBs) is necessary because some species have short-lived seeds (recalcitrant) such as cocoa, coconut, oil palm, rubber and many tropical fruits like mango, mangosteen, jackfruit, durian and rambutan. Seeds of some recalcitrant species can only be stored without desiccation for a few days, weeks or months (Roberts *et al*. 1984). Even if technology for conserving recalcitrant seeds is developed, there is still the problem with long regeneration cycle and which constraint utilization (Hawkes 1982). Hence, they are conserved in FGBs. FGBs may run a greater risk of being damaged by natural calamities, infection, neglect or abuse. *Ex situ* conservation of tree species using FGBs requires a substantial number of individual genotypes to be an effective conservation measure. Thus, FGBs require more space, especially for large plants such as coconut and they may be relatively expensive to maintain, depending upon the location and the complexity of alternative techniques available. However, FGBs provide easy and ready access to conserved material for research as well as for use. The advantages and drawbacks of FGBs are well debated (Engelmann 1999; Epperson *et al*. 1997; Saad and Ramanatha Rao 2001; Dulloo *et al.* in this chapter). However, it must be noted that, for a number of plant species, the alternative methods have not been developed to the stage where they can be effectively used (Ramanatha Rao *et al*. 1998; Engelmann and Engels 2002). Thus, the establishment of FGBs will play a major role in any conservation strategy for PGR.

Considerations for conservation of coconut germplasm in field genebanks

There are many field collections of coconuts in various countries, usually connected with coconut research institutes. According to the International Coconut Genetic Resources Network's (COGENT) Coconut Genetic Resources Database (CGRD), over 1416 accessions are collected and conserved in different genebanks around the world and all of these are maintained and managed in FGBs. At this stage, it must be noted that many of the plantings in these genebanks are often quite old and may originally have developed in a somewhat haphazard manner. Although they represent a commendable effort, there is a need to update the collections in a scientific manner, with due regard to thorough documentation of populations, and correct and foolproof labelling.

It is clear from the above discussion that the establishment of FGBs is the immediate option for the conservation and utilization of coconut genetic resources. In most annual crops like cereals and legumes, seed storage, multiplication and regeneration methods have been agreed upon (FAO/IPGRI 1994), but for crops like coconut, there are no such agreed methods. Hence, there is a need to look closely at scientific and practical criteria to be considered in establishing and managing a coconut field genebank. In the following sections, some of the issues involved in developing a successful field genebanking technique for coconut germplasm are discussed, much of which are based on Ramanatha Rao *et al*. (1998).

Genetic considerations

To effectively collect and conserve PGR, there is a need to have a sufficient understanding of some of the conservation genetic principles, especially those related to the structure and distribution of the genetic diversity of species to be conserved as well as the genetic diversity of the materials that are being conserved (for general principles, see Mohd Shukor Nordin and Mohd Said Saad 2001).

Ensuring genetic integrity and maintenance of genetic diversity

Breeding system. Generally speaking, populations of inbreeding species have a simple genetic structure, consisting of a number of inbred lines, genetically homozygous, several individuals representing each line in the population, some variations between lines, and very little heterozygosity. This makes conservation of mostly genetic resources self-pollinated species (in the case of coconut, the Dwarfs) much simpler, compared to outbreeding species (as Talls) in which, the population in general has higher within population variability. Maintaining this variation within a cross-pollinating species will be complex in terms of both germplasm collecting and regeneration and sampling for utilization.

Isolation. To be able to maintain the genetic integrity in an outbreeding species like coconut, especially the Talls, growing of accessions or populations in isolation should be considered. However, for practical reasons different accessions of coconut have to be planted together. Available information indicates that coconut pollen under natural conditions could travel over 300 metres (Mantriratne 1965; de Nucé de Lamothe and Rognon 1975) or assisted pollination (without bagging) results in pollen contamination, unless vary large plot sizes are used (de Nucé de Lamothe and Rognon 1975). Such large plot sizes may be impractical for a genebank.

Sampling and selecting entries. To establish a coconut collection, accessions displaying a range of diversity need to be planted. For this reason and from the point of population genetics, the principle of random sampling of genotypes from a given source population should be followed. However, in practice, both elite materials and genetic stocks are planted. Therefore, it is essential to sample a range of diversity to be represented in the FGB, including that of elite material. Thus, a coconut FGB can include populations/genotypes representing a range of diversity, elite materials, genetic stocks and some unique materials.

Sample and plot size. The size of the plot depends mainly on the breeding system and diversity in the sample and on the number of palms planted. It will be most appropriate if the material planted in a field genebank can be representative of the source population. For raising seedlings and transplanting, the best methods should be used to ensure maximum survival and vigour, any loss at seedling stage represents genetic drift (see below). Large plot sizes with high number of plants are appropriate for outcrossing species like coconuts, but for practical reasons, smaller plots are acceptable. However, if characterization and evaluation activities are combined with conservation then larger plot sizes, as dictated by statistical principles, should be used to avoid biases due to competition and xenia.

It is well established that square plots will be better than row planting for reducing pollen contamination (Breese 1989). The minimum number of palms per accession is determined by the number needed to represent the genetic diversity of the population while the resources available determine the maximum. Assuming that the material will be conserved for the next 200 years (with a frequency of re-planting in a FGB being 30 years for Dwarfs and 40 years for Talls), this gives about 4-6 regenerations (re-plantings). If the decision is to have a 90% probability of maintaining the alleles with a frequency of >5%, a population of about 40-60 will be needed per accession, and for an accurate characterization, about 90 palms are preferred. This is also based on the assumption that the seedlings for exchange or re-planting will be produced by (hand) pollinating the female parents with the mixed pollen of the accession/ population in question or by using methods such as chain crossing or pair crossing (For more information see Breese 1989; Crossa and Vencovsky 1994; Gale and Lawrence 1984; Gregorius 1991).

Production of seednuts through randomly chosen parents ensures a balanced representation of male parents thus increasing the effective population size (lowering the effect of drift) and provides pedigree information for subsequent breeding. This number needs to be supplemented with a few additional palms to compensate for any losses that may occur. From a conservation point of view, it may be better to plant and maintain equal number of plants for each accession, keeping in mind the need for representation of genetic variation. However, from the practical point of view, the number of palms of certain highly productive accessions may have to be increased to make the FGB commercially viable. Additional numbers of these accessions may best be planted in a separate area in the FGB.

Drift. Another consideration is avoidance of genetic drift or loss of rare but important genes or alleles from the population or accessions. For coconut, a minimum of 40 to 60 individuals are required to maintain alleles with 0.05 frequency with reasonable degree of confidence, to reduce the effects of genetic drift (again depending on the original sample size) and maintain genetic integrity. Assuming pollination is not controlled, there may be a need for some buffering or isolation to minimize random mating among the individuals of an accession. However, isolation between plots is hardly practised, hence, only a small number of plants in the middle of the plot may represent the gene frequencies of original populations. This would imply, especially if the original population size is large, that the total number planted in one block should be high enough to give sufficient number of plants to get an effective population size of at least 30, so as to sample/maintain alleles with frequency greater than 0.05. This would translate into a minimum of 100 palms in two blocks or replications of 50 each per accession, when no isolation or hand pollination is practised for the production of offspring generation (see below). It will be possible to have 60 palms in two replications of 30 each per accession, if isolation and/or hand pollination is practised.

Layout and plot management. Although as a general principle, it is best not to mix conservation and evaluation, planting equal numbers of palms per plot assists in evaluation and characterization of the material as well. Evaluation for important traits which are affected by environmental variation can only be carried out using replicated plots and also it must be kept in mind that the FGB needs to be protected from biotic and abiotic stresses, as far as possible, and this might result in poor quality of characterization and evaluation data. If evaluation is to be carried out in the FGB, it will be a good idea to plant each accession in at least two and ideally four replications depending on the total number of plants per accession. The accessions within each replication must be randomized. It is important to realize that, for purposes of conservation, planting sufficient number of plants (40-60) in a square block with a few metres border will be appropriate to reduce the chances of pollen contamination. Additionally, if these are planted in at least two replications, then evaluation of differences between populations, as well as selection of superior palms within populations may be combined with conservation. Since characterization and evaluation is involved, one has to consider soil heterogeneity as well. In controlling the soil heterogeneity, normally, allocating genotypes in a block is very effective if the number of genotypes involved is small. The effectiveness of controlling soil heterogeneity will be very much reduced if the number of genotypes is more than 20, especially for perennial crops that required a big plot size such as coconut. Under this situation, incomplete block designs could be used (Yap and Saad 2001).

Supply material from the FGB

From germplasm conservation and use point of view, it is important to supply a sample that represents the population conserved. If the progeny from an accession in the FGB is required, then it will be desirable to carry out hand pollination among the identified parent materials of an accession to produce the required offspring. Otherwise, from the standing population one will only get offspring resulting from open pollination, which may be contaminated from another accession. As described above, pollen of coconut can travel to significant distances resulting in considerable pollen adulteration. Coconuts are also known to be pollinated by insects such as bees, wasps and ants. However, it was observed that the insects tend to return to the same plant or to neighbouring plant, effecting mostly selfing or sibling, if the neighbouring plants belonged to the same population (Child 1964). Theoretically, if the plot size is very large, and the plots are separated by about 500 m, it may be possible to obtain less contaminated (by foreign pollen) nuts from the middle of the plot. However, such large plot sizes and growing in isolation are not practical. Thus, the most practical is hand pollination and bagging. From the point of genetic principles underlying regeneration, promoting random mating (i.e. using a mixture of pollen from different plants in the population, in this case, the plot) is recommended to increase the effective population size which can reduce the effects of genetic drift, while using pollen from single parent may be useful from the breeding point of view (Dr L Baudouin 1996, personal communication). It must also be noted that, in making controlled pollinations and comparing the offspring with its parents, one is not only able to preserve the genetic information of each individual but one may be able to keep the genetic information of the population as a whole.

One of the first to consider the genetic factors in maintaining living plant collections was Esser (1976). He concluded that true genetic conservation is not possible but one should know the boundaries and be able to channel plant conservation based on the knowledge and application of genetic parameters.

Agronomic considerations

Security from natural disasters and safety duplication

Despite many problems discussed, FGB is the current method for medium to long-term conservation and use. So the security of the site must be assured. Whenever possible, it may be appropriate to replicate the collections in more than one location. It is important to establish adequate safety duplicate collection(s) of the material maintained in FGB. Along with abiotic stresses like hurricanes, cyclones, drought, fire, etc., the biotic stresses such as pests and diseases can be continuous and serious threats to the germplasm being conserved. Therefore, the establishment of safety duplicate collections should be regarded as routine and budgeted for accordingly. The site should not be located in an area known for natural calamities or other disasters. This will help not only for effective monitoring and management of the FGB but also for the long-term safety of the material conserved.

Ecological adaptation

Close relationship between some characters in a population and its habitat in which the characters or traits have evolved and expressed has been reported many times in the literatures. Collections made from separate geographical areas can differ substantially. For instance, some characters are common in accessions collected from certain regions but not in the other region. Adaptability of the species or the accession to the location may be an important point to consider when long-term conservation is involved, especially in the case of regional genebanks. However, this may not be always possible as FGB may contain introduced or unadapted material. For efficient maintenance as well as from the point of view of use of the material conserved, it is important that the plants in the FGB be able to produce flower, fruit and set viable seed. If the site for the genebank is located in an area with (a potential for) commercial orchard plantation, then the value of the genebank would be even greater, in terms of use of the conserved material. The genebank can act as the nucleus and provide planting material for commercial plantations.

Minimal pest occurrence

It is essential to establish FGBs in areas that are relatively free from pests and diseases, especially those that are transmitted through propagules. This aspect will be discussed further under the section on germplasm health issues. Also, the site should be protected from animal pests such as wild pigs, porcupines, elephants etc.

Access to the FGB

To facilitate protection and management of the population stands, continued access to them must be assured. Therefore, the site chosen for FGB should be accessible and be near to the research station so that the material available can be effectively used. Also the material in the FGB can be monitored frequently. It should be possible for the genebank staff and other researchers to reach the site easily. From a practical point of view, this probably has an overriding importance.

Choice of material

Entries in regional genebanks

The major factors that control the choice of material into any genebank is determined firstly, by the needs of the users of that particular genebank and secondly, to have as much representation of genetic diversity and ecotypes that are available in the region. This requires giving emphasis to regionally recognized accessions. Therefore, there may be a tendency to acquire/assemble mostly the well-known elite accessions. However, it is important to have a balance between elite lines and accessions that represent a broader range of genetic variation from within the country as well as from the region. Giving due regard to the points mentioned earlier, it is important at the time of FGB establishment to plan for the materials to be included and lay out sufficient space. Care must be taken to insure that each accession included is unique and is not a duplicate.

Need for a national collection

Decisions will have to be taken on which accessions are to be maintained at the regional and national level. Some nationally important accessions or accessions representing national or narrow diversity may not be accommodated in the regional genebank for lack of space and resources. Such accessions must continue to be maintained in the national collection. In addition, it is essential to make sure that each accession is duplicated in another FGB for safety reasons, while other methods of conservation are being considered. The situation in any genebank is dynamic as new materials are collected for conservation. Therefore, it is essential to maintain space in the FGB for new accessions.

Policy and management issues

National, regional and international collections

Conservation of genetic resources is a long-term responsibility and requires long-term commitment of institutions and governments. It is for this reason that any conservation effort should be conducted within the framework of a national programme, that clear institutional responsibilities are assigned as part of a national mandate and that a reliable budget-line is established for continuous funding. At the regional and international level, the situation is different since it is not easy to assign clear mandates and responsibilities for the conservation of worldwide genetic resources of a specific genepool. The international germplasm collections held by the International Agricultural Research Centres are an exception as they have been placed under the auspices of the Food and Agriculture

Organization (FAO) as part of the International Network of *Ex Situ* Collections. Individual centres have accepted responsibility of conserving global genetic diversity for one or more specified genepools as part of their broader mandate to deal with the improvement of the so-called mandate crops.

Sustained commitment
It is important to critically examine the existing arrangements with regard to mandate and responsibilities at both the national and regional level for coconut genetic resource conservation. For example, the multi-site International Coconut Genebank (ICG) has been established in respective countries after an assessment of the level of governmental and institutional commitment to the maintenance of the collections. Only when an effective governmental commitment exists should the establishment or extension of a collection be considered. This is especially important for crops like coconut which needs a relatively large area in order to plant sufficient number of plants/trees necessary to represent the genetic diversity. Initial establishment costs, which in some cases can be very high, and recurring costs for maintenance of the collection should be considered at the planning stage and should be provided for. In many cases, the latter is ignored and the collections can run into problems within a few years of their establishment. Given this background, the establishment and maintenance of FGBs, appears to be more easily organized at national level, as part of national PGR programmes, rather than at regional or international level. In the case of regional or international efforts, it is essential to obtain the full support and commitment of the government of the host country in which the FGB is to be set up and to obtain commitments from the individual member states of the network to financially support the effort. For any emergency situation, provisions have to be made as to how and where the collection can be duplicated, if so decided. The role of the cooperating international institutions needs to be defined as well.

Legal issues
Since the CBD has come into force, countries now have the sovereign rights over the biological diversity present within their borders. In view of this, a clear consensus must be reached by all the member countries of a given crop genetic resources network with regard to sharing the benefits derived from the germplasm conserved, as well as, on access conditions to the conserved germplasm and information related to it as was done in the case of ICGs. The necessary agreements and mechanisms on access to and provision of accessions should be in place before the establishment

of a regional or international genebank. Within these mechanisms, there might be a need to develop some form of material transfer agreement to accompany germplasm accessions being sent to researchers/breeders within and outside the network.

Considering the current legal situation with regard to genetic resources, one of the options for regional or global PGR networks is to consider the possibility of placing their germplasm collections under the auspices of FAO, thus becoming part of the FAO International Network of *Ex Situ* Collections. In doing so, the host country which acts as trustee of the germplasm on behalf of all the member countries, agrees not to claim ownership over the germplasm and not to claim any form of intellectual property protection to the material or on any information related to it. The host country will also ensure that any further recipients of the germplasm are bound to the same conditions as mentioned above (FAO 1995). The ICGs are managed under the auspices of FAO.

Germplasm health issues

There are two reasons for establishing FGBs in areas free from important pests and diseases. One is the risk of the entire collection, or part thereof, being destroyed by pests or diseases. The other is the risk of spreading pests and pathogens to new areas, which may easily happen with germplasm (Hewitt and Chiarappa 1977). An effective quarantine system should act as a filter, and should not be a barrier to germplasm exchange. However, as some countries have stronger controls than others, breeders and the germplasm community have a certain responsibility to give due attention to pathogens. For example, FGB managers should apply restrictions to the international (or even national in the case of large countries and where there are clear regional differences in the occurrence of a particular pest) movement of seednuts and choose instead the movement of embryo cultures even if local quarantine authorities do not impose such restrictions.

Obviously, before establishing a field genebank, a critical evaluation of the disease situation in the location concerned will be required. Often parts of countries are free from a reported pathogen (e.g. Cadang-cadang) is not reported in Mindanao and the northern part of Luzon in the Philippines (Hanold and Randles 1991a) or Kerala wilt is only reported to occur in parts of Kerala and Tamil Nadu (Frison *et al.* 1993). A list of coconut diseases of uncertain etiology is given by Frison *et al.* (1993) and special care needs to be taken with regard to these diseases. An inverse case exists with the reports of viroid-like sequences in coconuts, which could not yet be linked with clear disease symptoms (Hanold and Randles 1991b; Fassil and Diekmann 1995). In the case of lethal yellowing and related diseases, it appears that a group of at least three closely related strains of phytoplasmas can be considered the causal agents (Jones *et al*. 1995). The general recommendation is to move embryo cultures or pollen, and not seednuts. Based on this, establishing embryo culture facilities in connection with FGB and providing the necessary training becomes very important.

Germplasm health aspects need to be considered not only at the point of exchange, but also at any stage of germplasm management. During collecting, care must be taken that germplasm is collected only from healthy palms. In the regeneration and multiplication process, plant protection measures including pesticide application may be required. If an evaluation of traits like resistance to pathogens is done under conditions of high disease pressure (e.g. with artificial inoculation), a careful evaluation of the material with regard to its use in regeneration or exchange is essential.

Summary and conclusion

In the discussion presented here, it has been assumed that the collecting has been effectively carried out; keeping the sampling of genetic diversity in mind, and that all quarantine requirements have been completed. To establish, maintain and manage a FGB for coconut (national or regional collection), the following critical steps (checklist) are suggested (Ramanatha Rao *et al*. 1998):

A. Agreement on precise functions of the collection:
1. Selection of site, based on the criteria established;
2. Agreement on obligations and responsibilities of organizations and/or countries involved;
3. Establishment of infrastructure and facilities; and
4. Legal aspects and exchange protocols (ownership, conditions of release, IPR issues, benefit sharing, use of MTA and other mechanisms) as agreed by all partners;

B. Establishment of a coconut FGB:
5. Assure comprehensiveness of collection by including as much genetic diversity as appropriate;
6. Consider carefully the sampling techniques (random vs. non-random, and the need for deviation);
7. Assure that there is no duplication of accessions as this directly increases cost of FGB;
8. Determine the need for having replications, the number etc., based on the objectives of FGB;

9. Determine through discussions and by actual visitations the accessions and the number of accessions to be included in FGB, and number of plants per plot;
10. Establish nursery of vigorous and healthy seedlings raised from nuts produced through hand pollination, determine planting conditions, etc. depending on the location of FGB;
11. Lay out square blocks of equal size;
12. Plan space for present and future accessions (as much as possible) to be randomized in the FGB;
13. Follow all protocols for safe movement of germplasm;
14. Ensure that embryo culture/tissue culture facilities can be put in place for exchange of material; and
15. Accept more material into FGB as they become available by going through all the steps discussed;

C. Maintenance of a coconut FGB:

16. Take all the necessary agronomic and plant protection measures to maintain a healthy stand of coconut palms;
17. Take all the measures feasible to protect FGB from adverse environmental conditions, physical stresses, etc;
18. Make sure that a safety duplication is established and all the needs of health care are fulfilled;
19. Document all accessions as well as activities carried out in FGB by establishing and running an appropriate information management system; and
20. Provide linkages to other methods of conservation, if any, such as *in vitro* conservation of zygotic embryos, pollen preservation, etc;

D. Access to material in FGB:

21. Ensure physical availability of the material;
22. Keep the plants in healthy condition;
23. Facilitate nut/seedling production through hand pollination for distributing germplasm as agreed at the time of the establishment of the genebank;
24. Characterize/evaluate the material in FGB according to agreed principles;
25. Provide for production of nuts through hand pollination, rather than harvesting from the centre of plot to be certain of purity of the material;
26. Make available the information on the material conserved in the FGB to all users; and
27. Exchange material using embryo culture rather than seednuts.

This is by no means an exhaustive list of steps to be taken but only the important considerations that determine the effectiveness and sustainability of the FGB. It was also assumed that the issues considered in the earlier discussion were taken into account, decisions have been made and the consequences noted. Some of the principles of agronomy, nursery management, etc. can be found in Santos *et al*. (1996).

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COGENT's multi-site International Coconut Genebank

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Background of COGENT

In 1992, the Consultative Group on International Agricultural Research (CGIAR) decided to include coconut in its research portfolio after studies indicated that international support and global coordination of research in coconut is essential to make coconut more productive and beneficial to small-scale coconut farmers. The CGIAR and its Technical Advisory Committee (TAC) recognized that international support to coconut research was needed as many coconut-producing countries lacked both the human and material resources to conduct expensive and time-consuming research. Thus, it tasked the International Plant Genetic Resources Institute (IPGRI) to undertake research on coconut genetic resources, which the CGIAR identified as one of the five priority research areas that deserved international support. Accordingly, IPGRI included coconut genetic resources in its plant genetic resources research programme and organized the International Coconut Genetic Resources Network (COGENT) to implement this mandate. Starting with 15 countries, COGENT has rapidly developed into an active global network currently involving 38 coconut-producing countries (Table 1).

Table 1. COGENT member countries

Southeast and East Asia	South Asia	South Pacific	Africa/Indian Ocean	Latin America/ Caribbean
1. China	1. Bangladesh	1. Cooke Islands	1. Benin	1. Brazil
2. Indonesia	2. India	2. Fiji	2.Cote d'Ivoire	2. Colombia
3. Malaysia	3. Pakistan	3. Kiribati	3. Ghana	3. Costa Rica
4. Myanmar	4. Sri Lanka	4. Papua New Guinea	4. Kenya	4. Cuba
5. Philippines		5.Solomon Islands	5. Madagascar	5. Guyana
6. Thailand		6. Tonga	6. Mozambique	6. Haiti
7. Vietnam		7. Vanuatu	7. Nigeria	7. Honduras
		8. Samoa	8. Seychelles	8. Jamaica
			9. Tanzania	9. Mexico
				10.Trinidad-Tobago

COGENT's goal is to improve coconut production on a sustainable basis and increase income of coconut farmers and growers in developing countries through improved cultivation of the crop and efficient utilization of its products. The objectives of COGENT are:

1) To establish and maintain an international database on existing and future collections;
2) To encourage the protection and use of existing germplasm collections;
3) To identify and secure additional threatened diversity by developing and adopting suitable technologies and conservations strategies;
4) To promote greater collaboration among research groups in producer countries and advance technology sources in the exchange of germplasm and the development of new techniques;
5) To conduct appropriate training and information dissemination; and
6) To secure necessary funding for network activities.

In the last 12 years, COGENT has generated modest but significant achievements. The network has been successfully established with a Steering Committee serving as its supervisory and policy making body and is fully operational with 38 coconut producing countries as members. The International Coconut Genetic Resources Database (CGRD) has been established that currently contains passport and characterization data of 1416 accessions conserved in 25 sites in 23 countries. In addition, 278 ecotypes from the Asia Pacific region have been collected and conserved. To further secure conserved germplasm, a multi-site International Coconut Genebank (ICG) is being established to conserve 200 important accessions in the regions in which COGENT operates, which is hosted by India, Indonesia, Papua New Guinea, and Côte d'Ivoire and Brazil (under negotiation). An additional 212 farmers' varieties have been identified and are currently being characterized. Multipurpose uses of coconut varieties are also being documented and promoted. The performance of 34 high-yielding hybrids are being evaluated in multilocation hybrid trials in four African and three Latin America/ Caribbean countries to select varieties and hybrids that are suited to particular agroecological conditions and to determine germplasm x environment interaction. Farmers' varietal preferences in 15 countries are being evaluated. Diversity-linked income-generating activities have been initiated in 15 countries as part of a strategy to promote *in situ* and on-farm conservation, and germplasm utilization. Protocols for embryo culture, cryopreservation, morphometric and molecular marker-based methods for locating and characterizing diversity, assessing pest risks and managing germplasm health are being developed, tested and upgraded. Strategies and techniques for farmer participatory research, collecting, characterization, and e*x situ* and *in situ* conservation are being refined.

To strengthen coconut research capability of COGENT member countries, IPGRI and COGENT have, as of 2003: organized 39 country missions involving 28 experts to help COGENT member countries conduct research needs assessment and to identify priority research and training activities; conducted 41 workshops and meetings involving 994 coconut researchers to share information and technologies, discuss issues and common problems and opportunities and how to address them; conducted 40 training courses involving 765 participants from 41 countries; supported 180 research projects in 30 member countries; and led in establishing the Global Coconut Research for Development Programme (PROCORD), a global coconut research alliance with the Bureau for the Development of Research on Perennial Tropical Oil Crops (BUROTROP) and the Asian and Pacific Coconut Community (APCC). COGENT's current priority involves the further promotion of more effective conservation and use of coconut genetic resources, both regionally and globally. This includes the establishment and operation of COGENT's multi-site International Coconut Genebank (ICG).

Integrated approach to coconut conservation

COGENT's conservation strategy is anchored on promoting the sustainable protection of diversity as well as maximizing germplasm use. In developing its conservation strategy, COGENT recognized that no one method or approach of conservation can meet all conservation needs and that there is a need to employ a combination of methods to ensure the sustainable conservation of as much genetic diversity as possible. It actively encourages the participation of its member country governments, partner organizations in both developing and developed countries, non-government organizations (NGOs) and coconut farmers themselves in conserving germplasm. The components of COGENT's conservation strategy consist of:

1. Conservation in national collections;
2. Conservation in the multi-site ICG;
3. *In vitro* embryo culture and cryopreservation;
4. *In situ* and on-farm conservation; and
5. Promoting conservation through use by developing and implementing a globally-coordinated coconut breeding programme, establishing farmer community-managed coconut seedling nurseries in at least 25 countries, linking germplasm conservation and use with the broader areas of research and

development assigned to BUROTROP (agro-physiology and crop protection) and APCC (processing and marketing), developing and disseminating catalogues of conserved germplasm and farmers' varieties, and upgrading and widely disseminating the CGRD.

Conservation in the multi-site International Coconut Genebank

Rationale

World coconut production is declining due to ageing palms, natural calamities, inadequate replanting programme, lack of suitable planting materials, poor crop management, population pressures causing crop shifts, and lack of capital for farmers to invest in coconut production. The development and use of improved coconut cultivars can markedly help solve these problems and promote increased coconut production. However, the landraces of coconut (ecotypes), which contain important genetic characters for yield, disease and pest resistance and adaptation, are under treat to genetic erosion and need to be collected, conserved, evaluated and shared more widely to develop improved varieties.

Conservation and use of a wide range of coconut diversity is faced with several constraints. First, while national coconut field genebanks are important sources of germplasm for exchange among COGENT member countries, many countries still lack the necessary economic and technical capacities to maintain their conserved germplasm. Second, many countries do not have the capacity to evaluate the performance of their germplasm while the data obtained are often not comparable. Third, multi-country negotiations for obtaining germplasm are often difficult for national breeding programmes needing to import germplasm that belong to several countries. Fourth, many researchers, who may want to share their germplasm, do not have the needed policy cover and their countries generally lack the needed facilities for ensuring the safe movement of coconut accessions. Fifth, COGENT does not have a concrete mechanism that would facilitate access and safe movement of germplasm to its member countries.

To address these constraints, the COGENT Steering Committee decided to establish a multi-site ICG in 1995. Subsequently, site assessment surveys were conducted to evaluate the suitability of proposed regional genebank sites in the five host countries of Indonesia, India, Papua New Guinea, Côte d'Ivoire and Brazil. During the International Coconut Genebank workshop held from 26 to 28 February 1996 at Pekanbaru, Riau, Indonesia, representatives of IPGRI, the Centre de Cooperation Internationale en Researche Agronomique pour le Development (CIRAD) and the World Bank worked with representatives of COGENT member countries in developing a series of legal agreements, initial work plans and proposed budgets, using national funds for each of the initial four genebanks to be hosted by Indonesia for Southeast and East Asia, Papua New Guinea for the South Pacific, India for South Asia and Côte d'Ivoire for Africa and the Indian Ocean.

Objectives and initial activities

The objectives of the ICG are: 1) to conserve nationally- and regionally-identified diversity; 2) to conserve internationally identified diversity; 3) to further assess the diversity, evaluate the performance of the conserved germplasm and disseminate related information to coconut-producing countries; 4) to make germplasm materials available to interested coconut-producing countries in accordance with existing protocols; and 5) to conduct research and training in relation to the above.

Memoranda of Agreements (MOAs) for hosting of the ICGs for Southeast and East Asia (Indonesia), South Asia (India), South Pacific (PNG) and Africa and the Indian Ocean (Côte d'Ivoire) were developed and signed by the host countries and IPGRI on behalf of COGENT, with the Food and Agriculture Organization (FAO) of the United Nations serving as trustee. All MOAs were worded similarly (see MOA for ICG-SP in Annex 1.1). Negotiations are underway for Brazil to host the ICG for Latin America and the Caribbean. The host countries agreed to commit resources for their establishment maintenance and data gathering. The existing national field collections of Côte d'Ivoire and Papua New Guinea were donated to the ICG. However, COGENT is also exerting efforts to source additional funds for the maintenance of collections. COGENT has developed a sustainability strategy for the ICGs consisting of the following:

1) MOA committing host countries to maintain the field genebanks;
2) Negotiations for income from the ICG to be used for maintenance;
3) Superimpose research and training onto the ICG to share the cost of administration and maintenance;
4) Charge requesting countries for the cost of preparation, shipment and maintenance of germplasm, the latter on a pro-rata basis;
5) Undertake income generating activities in ICG plantations such as the production and marketing of high-value products from all parts of the coconut and integrate with intercropping and livestock raising as appropriate;
6) Generate external donor support; and
7) Generate national and provincial/state funding and institutional support.

The sites for ICG were chosen based on surveys conducted by coconut experts who considered and evaluated several important selection criteria.

Thus, the basic needs of field genebanks such as safety, security, accessibility, environment, etc. have been established. Among several items that were considered, two principles were highlighted. First, the choice of material in the ICG was determined by the needs of the users and by the need for as much representation of genetic diversity and ecotypes as possible. The importance of having a balance between elite lines and accessions that represent a broad range of genetic diversity from within the country as well as from the region was recognized from the beginning. Care has been taken to ensure that each ICG accession is unique and is not a duplicate. Thus, current accessions are being further validated using molecular marker studies to eliminate duplicates. Second, decisions were made as to which accessions would be maintained regionally and nationally. It was agreed that the nationally important accessions that cannot be accommodated in the regional genebanks would be maintained in the collections of strong national programmes. Thus, from the beginning it was apparent that national collections and the ICG would complement each other to accommodate as much coconut genetic diversity as possible.

It is envisioned that the ICG at each regional site will conserve in field genebanks about 200 accessions which are important to the region. The ICG field genebanks are part of the *ex situ* collection under the International Undertaking on Plant Genetic Resources. The designated germplasm are conserved in the field genebanks and shared with coconut growing countries based on material transfer agreements. The field genebanks are established and managed by national programmes under the oversight of COGENT and IPGRI. Laboratories and facilities will also be developed to further locate diversity, identify and eliminate duplicates, conduct disease indexing, process pollen and embryos for export, conduct cryopreservation and train coconut researchers from member countries in evaluating, conserving and using germplasm. Thus, each site of the ICG will be developed as Centres of Excellence in concurrence to IPGRI's initiatives of building and upgrading the capacity of partner institutions.

Germplasm conservation and sharing

In the next seven years (2004-2010), the ICG host countries aim to conserve in respective regional field genebanks a maximum of 200 accessions each, which will be contributed by coconut-producing countries in each region. Accessions will be imported in the form of excised embryos, grown *in vitro* in the embryo culture laboratory, transferred into pots in the greenhouse and eventually transplanted in the field. These accessions, which will be planted in the field genebank of about 200 hectares, will be characterized and evaluated using agronomic and molecular data to determine their diversity, performance and potential for improvement work. Four types of coconut accessions will be conserved in the ICG: 1) major varieties (parents of existing hybrids and advanced generations of selected cultivars); 2) varieties/cultivars threatened with genetic erosion or total loss; 3) varieties/cultivars with special traits/genetic markers; and 4) genotypes being used for current genetic diversity studies using molecular markers.

Member countries of each region can access germplasm belonging to different countries by negotiating with each ICG host country. The requested accessions will be sent in the form of embryos or pollen to interested countries after disease indexing to ensure safe movement. Requesting countries will be charged the cost of producing the seednuts and for preparing the embryos as well as the pro-rata cost of maintenance, disease indexing and shipping. These germplasm transfers will be covered by Material Transfer Agreements (MTA).

Initial achievements

Under COGENT, ICG sites in four host countries have been strengthened to some extent [i.e., ICG-South Asia (India), ICG-Southeast and East Asia (Indonesia), ICG-South Pacific (Papua New Guinea), and ICG-Africa and the Indian Ocean (Côte d'Ivoire)]. IPGRI has supported the ICGs in capacity building for embryo culture technology, in terms of materials, skills and laboratory upgrading to prepare them for importing and maintaining germplasm from network member countries in their respective regions. They have also been trained on germplasm collecting, morphometric and molecular marker (microsatellite kits) methods of germplasm characterization, genebank management and on cryopreservation. Since COGENT is currently an open network, it was proposed to further strengthen germplasm conservation by executing a formal Memoranda of Agreement with COGENT member countries, at the highest government level, to formalize their membership in COGENT and to formally commit access to their coconut germplasm.

Despite meager resources, the ICGs have made some significant achievements. Table 2 shows the date of signing of the hosting agreements and the status of conserved germplasm in each of the host countries.

Plan of action for the International Coconut Genebank

As part of the above-described conservation strategy for coconut, IPGRI and COGENT would like to undertake the following plan of action for the upgrading of the ICG in the next seven years:

1. Regeneration of old palms of 50 accessions in the ICG for Africa and the Indian Ocean;
2. Additional morphometric and molecular marker characterization

Table 2. Germplasm conserved in the multi-site ICG

Name of Genebank	Date of MOA signed	Initial number in list of designated germplasm	Designated germplasm currently conserved
International Coconut Genebank for the South Pacific (Papua New Guinea)	30 September 1998	55	50
International Coconut Genebank for South Asia (India)	30 October 1998	49	46
International Coconut Genebank for Southeast and East Asia (Indonesia)	26 May 1999	52	29
International Coconut Genebank for Africa and The Indian Ocean (Côte d'Ivoire)	14 October 1999	49	99*

** Includes additional accessions entered into the ICG after the signing of the MOA*

of the 1416 accessions conserved in the national collections of 23 countries to select other entries for the ICG and to upgrade the CGRD; and of the 224 accessions in the ICG to identify duplicates;

3. Integration of the CGRD with the System-wide Information Network for Genetic Resources (SINGER), the CGIAR-supported system-wide genetic resources programme;
4. Importation and establishment of additional accessions into the ICG sites to complete the 200 accessions per site;
5. Upgrading of pollen processing and embryo culture laboratories, net houses and coconut seedling nurseries in each ICG site;
6. Establishment of the needed facilities in the ICG host countries (i.e., molecular marker laboratories, except for ICG-Africa and Indian Ocean; disease indexing laboratories; training and dormitory facilities);
7. Research and training support for the following strategic activities: somatic embryogenesis, embryo culture, molecular marker/ microsatellite research, pest risk assessment and germplasm health management, germplasm x environment interaction and genetic distance analysis of conserved germplasm, and globally-coordinated coconut breeding; and
8. International Coconut Genebank evaluation and meeting of stakeholders.

Conclusion

Two of the major priorities of IPGRI and COGENT are: (1) saving threatened diversity and (2) promoting the use of conserved materials for developing improved varieties for national programmes and small-scale farmers. Thus, accelerated effort is being placed on the movement of germplasm from COGENT's member countries to their regional ICG and the provision of breeding materials from the older ICG (i.e., Côte d'Ivoire and Papua New Guinea) to member countries and soon, from the other ICG host countries where some of the new conserved materials are now starting to bear fruits.

While IPGRI/COGENT desires to implement a progressive germplasm movement initiative, at the same time, it would like to ensure that this is done in a safe manner to protect the coconut industry of receiving countries. Thus, IPGRI approached the Australian Centre for International Agricultural Research (ACIAR) to fund the development and publication of a manual on Germplasm Health Management for COGENT's multi-site International Coconut Genebank. ACIAR has agreed to support this very important and strategic initiative. This manual will be useful as a guide to genebank managers and plant quarantine officers worldwide in making informed decisions on the safe movement of coconut genetic resources.

The International Coconut Genebank for the South Pacific (Papua New Guinea)

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In August 1995, the COGENT Genebank Task Force visited PNG to evaluate the suitability of the proposed site and the commitment of the PNG government. The proposed genebank site is the Murunas plantation currently named Stewart Research Station of the PNG Cocoa and Coconut Institute (CCRI) in Madang, which has a total area of 450 ha, 200 ha of which was made available for the ICG. The CCRI staff and laboratories in Rabaul will provide support to the field genebank in Madang. The larger vegetation was cleared in 1993 and the secondary growth will be cleared as needed. Drainage canals will also be constructed as needed.

The annual rainfall is 3500 mm, evenly distributed, and the soil is mostly silty clay loam. Following the successful site suitability evaluation and COGENT's acceptance, the PNG Stewart Station's coconut genebank has been transformed into the International Coconut Genebank for the South Pacific (ICG-SP), which to date conserves a total of 50 designated germplasm.

The Memorandum of Agreement to establish the ICG-SP was signed in November 1998 between the Government of PNG, IPGRI on behalf of COGENT and the Food and Agriculture Organization (FAO) of the United Nations serving as trustee. The list of initial designated germplasm as stipulated in the signed MOA is shown in Annex 1.2.

Since 1994 to 2004, 10 specialists visited PNG on eight technical assistance missions including assessing the country's coconut R&D capability and assist the national programme in identifying common problems and opportunities for network collaboration, identifying a suitable site for ICG-SP, evaluating embryo culture laboratories and training their staff, evaluating COGENT's germplasm collecting and conservation strategies, assessing the pest risk for the ICG-SP, assisting in the installation of machineries and training in the production of coconut virgin oil, fiber-based products and coconut candies.

To date, IPGRI/COGENT has helped the ICG-SP established an embryo culture laboratory which is currently fully operational with additional stocks of glassware and chemicals purchased and a seedling nursery for *ex vitro* seedling production established in June 2001. It has also supported the training of ICG staff on embryo culture, genebank management, germplasm characterization using morphometric methods and molecular marker (microsatellite kits) methods. In addition, six local coconut researchers have undergone staff development training sponsored by COGENT on topics such as the standardized research techniques in coconut breeding (STANTECH); coconut collecting and conservation; coconut data analysis; computer use, documentation, data analysis, dedicated statistical software; and coconut cryopreservation.

The ICG-SP contains important germplasm from the fragile ecosystem of the South Pacific. These include typhoon-resistant accessions with big trunks and fruits, which are suitable for the Pacific islands. In the last two years, through COGENT-CIRAD collaboration, precious coconut populations from Cooke Islands, Fiji, Kiribati, Marshall Islands and Tuvalu have been collected, which were not previously available. A total of 13 accessions from four atoll countries (Tuvalu, Kiribati, Cook Islands and Marshall Islands) were collected by the CIRAD/COGENT team, embryo cultured and initially grown *in vitro* at the laboratories of the Secretariat of the Pacific Community (SPC) in Suva, Fiji and subsequently sent to the ICG–SP in 2000/2001. These accessions, which were collected to prevent losing them from the threat of global warming and possible water rise, were grown in the embryo culture laboratory and nursery and planted in the field. Other germplasm from other Pacific countries will also be imported when funds become available. A total of 62 embryos from one accession (Fiji Tall) were provided by Fiji in March 2002. The imported germplasm are currently being maintained in the laboratory using the upgraded coconut embryo culture protocol. Most of the evaluation work on the performance of the germplasm is being carried out in the field.

Recently, a report was received from ICG-SP Papua New Guinea stating that frequent power outages, have been posing a serious threat to the operations of the embryo culture laboratory and causing damage to the embryo-derived plantlets. The PNG Cocoa and Coconut Institute (CCI) and the Secretariat of the South Pacific Commission requested the assistance of COGENT and IPGRI to enable the institute to purchase a standby generator. In response to this request, IPGRI/COGENT co-financed with CCI the purchase and installation of a standby generator. The generator is currently being used to support the air conditioners and other equipment of the embryo culture laboratories in case of power interruptions.

The International Coconut Genebank for South Asia (India)

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The Central Plantation Crops Research Institute (CPCRI) hosts the International Coconut Genebank for South Asia (ICG-SA). The field genebank in Kidu Farm, Karnataka, which is the ICG-SA field genebank, is supported technically by the laboratory facilities at CPCRI, Kasaragod. CPCRI maintains the world's largest assemblage of germplasm by undertaking the planting and maintenance of the field genebank and activities on embryo culture, assessment of diversity using molecular markers and disease indexing. The National Bureau of Plant Genetic Resources (NBPGR), New Delhi, collaborates with CPCRI on cryopreservation activities.

In July 1995, the COGENT Task Force evaluated the forested area adjacent to the CPCRI Seed Farm in Kidu, the genebank site proposed by the government of India, and found it suitable. The Kidu field genebank is situated in Dakshina Kannada District of Karnataka about 90 km east of Mangalore and about 100 km east of Kasaragod. The farm lies between 12.30°N and 75.20°E at an elevation of 291 msl. The summer temperature range between 33 and 40°C and the winter temperature is between 22 and 18°C. The soil is mostly red lateritic, changing to alluvial laterite towards the riverbank. The average annual rainfall is 2900 mm with a river on the southern farm boundary as perennial source of irrigation water. Irrigation is essential as the site has a distinct dry period. Since the proposed site is within a forest without any coconut plantation nearby, the risk of disease spread from neighboring plantations is minimal. The nearest root wilt affected area is 650 km from the site and the disease is said to have moved only 100 km during the last 120 years.

The Memorandum of Agreement for the establishment of the ICG-South Asia was signed by the Government of India, IPGRI on behalf of COGENT and FAO as trustee in October 1998. The list of initial designated germplasm during the signing of the MOA is shown in Annex 1.3. To date, India has conserved a total of 46 of designated germplasm in the ICG-SA. Nearly 30 ha of forestland have been cleared and surrounded with electric fencing for planting. Furthermore, drip irrigation has been provided to 2700 seedlings that have been planted there.

IPGRI/COGENT has helped the ICG-SA in collecting germplasm from the Indian Ocean Islands of Maldives, Comoros, Madagascar, Reunion and Seychelles. A total of 746 embryos were collected from Sri Lanka as of February 2001. Out of these, a total of 396 embryos were damaged. A total of 401 embryos were collected from Bangladesh during November to December 2001, of which 157 embryos survived. The embryos were collected from the following varieties: Chinasukanya, Chinasukanya Dwarf Orange, Pubail Tall, Kayemkola Tall, Bagharpara Tall, Rupdia Tall, Khairtala Tall and BARI Narikel-I, BARI Narikel-II, Uzirpur Tall and Agailjhara.

In 2003, 34 collections were added to the existing collection. These included five collections from Goa, six from Maharastra, eight from Assam, four from Sri Lanka and 11 from Bangladesh. The collections from Sri Lanka and Bangladesh were in the form of zygotic embryos. These embryos cultured *in vitro* were rooted and later planted in pots. Conservation of coconut germplasm in the form of *in vitro* culture is being attempted at CPCRI, Kasaragod. Furthermore, a total of 4962 inter-crossed nuts from 31 accessions were also sown to generate planting materials at the ICG-SA. To produce additional seednuts, a total of 3004 female flowers were pollinated from eight accessions for regeneration.

From 1995 to the present, seven coconut specialists visited India to help identify a suitable site for the ICG-SA; evaluate COGENT's collecting strategies; and conduct a pest-risk assessment for the genebank. In 2000, a regional training course on *In Vitro* Conservation and Cryopreservation on PGR was conducted by NBPGR with seven participants from five COGENT member countries. Another eight local staff from various collaborating institutions and NARS were trained on various topics including the use of the manual on standardized research techniques in coconut breeding (STANTECH), *in vitro* embryo culture and cryopreservation techniques as well as the use of the microsatellite kit and dedicated statistical software.

The International Coconut Genebank for Southeast and East Asia (Indonesia)

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The International Coconut Genebank for Southeast and East Asia (ICG-SEEA) is hosted by the Indonesian Agency for Agricultural Research and Development (AARD) using the field genebank in Pekanbaru, Riau Province; experimental gardens in Manado, North Sulawesi; and AARD laboratory facilities in Bogor, West Java and in Manado, North Sulawesi.

In July 1995, the COGENT Task Force evaluated the proposed site at Sikijang Mati, Pekanbaru, Riau Province in Central Sumatra and found it to be generally suitable and made some suggestions for improvement. The site is located 20 km from the city of Pekanbaru, the capital of Riau. Pekanbaru has regular flights from Jakarta (1.5 hours) and Singapore (30 minutes), as well as other cities in Sumatra. The annual rainfall is about 2000 mm, well distributed over the year. The topography of the area is undulating and most of the land is covered by secondary forest, with small rivers. The soils are yellow to yellow-red podzolic, low in organic matter and with pH of around 5.0. The soils are generally very poor and unsaturated but they make a good substratum for the crop to grow and respond well to the application of fertilizers, which are readily absorbed by the crop. Since the area was not very uniform, the Task Force recommended that a detailed survey be undertaken to select only those areas where soils are generally good and more than one meter deep to avoid the hard pan. About 1000 ha of secondary forest has been offered by the Government of Indonesia which could be used for the ICG (200 ha) and the rest for production area to generate income for the maintenance cost of the ICG.

The Memorandum of Agreement for the establishment of the ICG-Southeast and East Asia was signed by the Government of Indonesia, IPGRI on behalf of COGENT and FAO as trustee in May 1999. The function of the coconut collection at Sikijang was not only for germplasm conservation, but also for genetic evaluation and utilization. To date, Indonesia has conserved a total of 29 of the designated germplasm in the International Coconut Genebank for Southeast and East Asia at Sikijang. The list of initial designated germplasm during the signing of the MOA is shown in Annex 1.4.

Due to the financial crisis in 1997 and the resulting lack of government budget, there was slow development of the Sikijang area, resulting in the squatting of the remaining areas by surrounding inhabitants and migrants. Two extension ICG areas have therefore been identified: the Paniki Experimental Garden (100 ha) located beside the Indonesian Coconut and Other Palmae Research Institute (ICOPRI) in Manado, and the Pandu Experimental Garden (80 ha) which is about 18 km from the ICOPRI office and belonging to the Balai Pengkajian Teknologi Pertanian (BPTP). The soil and climate there are very suitable for coconut growing. Therefore, it was recommended that the main part of the ICG-SEEA be moved from Sikjiang to North Sulawesi. However, the 29 accessions which have been collected will remain in Sikijang and maintained by the Indonesian Government.

To date, a total of four accessions have been received from Malaysia, six from China and 10 each from the Philippines, Thailand and Vietnam, respectively. A total of at least 100 accessions have been conserved from Indonesia from 1996 to 2001. Twenty-nine of these 100 accessions have been planted at Sikijang, Pekanbaru, Riau, which was the initial identified site for the ICG-SEEA. In addition, a total of 460 embryos of Malayan Tall and 469 embryos of Malayan Green Dwarfs were received from Malaysia and successfully cultured *in vitro.*

IPGRI/COGENT has supported the ICG-SEEA in collecting germplasm from the Moluccas Island, East Timor, West Nusa Tenggara, Sangir Talaud Islands, Salibabu Island, Buol District, Central Sulawesi, Sangir Talaud district and North Sulawesi.

From 1995 to 2000, 11 specialists have visited Indonesia to help the country in its coconut PGR activities. These include identifying a suitable site for the ICG-SEEA, collecting leaf samples for electron microscopy detection of mycoplasma, identifying marketable alternative products for coconut as well as suitable varieties for these products, evaluating COGENT's collecting and conservation strategies, assessing pest risk and evaluating the progress of the ICG, and assisting in the installation of equipment for feasibility studies.

Four training courses were held in the country, whereby 52 researchers from nine countries attended. The training courses, which were funded by the Asian Development Bank (ADB), were hosted by ICOPRI (formerly the Research Institute for Coconut and Palmae or RICP). IPGRI/COGENT has also sponsored 20 local researchers and specialists for staff development training in coconut data analysis, coconut collecting and conservation, embryo culture, technical writing/seminar presentation and proposal writing, the use of the microsatellite kit and others which are related to the COGENT's poverty reduction project.

The International Coconut Genebank for Africa and Indian Ocean (Côte d'Ivoire)

JL Konan
Head, Coconut Research Programme, Centre National de Recherche Agronomique (CNRA), Marc Delorme Station, Côte d'Ivoire

The ICG-AIO is hosted by the Marc Delorme Coconut Research Station in Côte d'Ivoire which has a total area of 1200 ha. The soil of the station is composed of alluvial deposits of tertiary sands with 8-10% clay, poor in organic matter and minerals. The climate is characterized by two dry seasons of different lengths, one from December to April and the other in August to September which alternate with two rainy seasons. The mean annual rainfall is 1800 mm.

The MOA for the establishment of the ICG-AIO was signed in October 1999 by the Government of Côte d'Ivoire, IPGRI on behalf of COGENT and FAO as trustee. At the time of the signing of the MOA, the coconut genebank of the Marc Delorme Coconut Research Station was converted into the ICG-AIO. The list of initial designated germplasm during the signing of the MOA is shown in Annex 1.5.

To date, ICG-AIO has a total of 99 accessions. Furthermore, five Tall varieties from Sri Lanka, Tonga, Vanuatu, Tagnanan and Rotuma were received and planted on eight hectares for their renewal. A total of 3400 embryos were provided to CIRAD/IRD Montpellier for *in vitro* culture technique development. Seednuts were also provided to participating countries in the CFC-funded multilocation hybrid trials of IPGRI/ COGENT. A researcher from the Centre National Agronomique (CNRA) has visited the five other participating countries (Benin, Tanzania, Brazil, Mexico and Jamaica) to help in the project trial implementation.

Two researchers from Marc DELORME visited the western region of Ghana as part of its collaborative research activity on lethal yellowing disease. Twelve kilograms of VTT (Vanuatu Tall) pollen were also provided to the Ghana coconut programme per year to produce lethal yellowing-tolerant hybrids. For 2004, nine Dwarf varieties from the ICG-AIO were selected to be tested also against the disease. Marc Delorme Station also received two research teams, from Senegal and Mayotte Island to help them in coconut development. A total of 70 800 seednuts of improved varieties were produced for smallholder farmers and the industrial sectors in the country. For Nicaragua (Coconut Research Institute or CRI), 1200 grams of Panama Tall Monagre pollen have been provided per year to allow appropriate hybrids production. About 9500 seedlings of improved Mawa (PB121) hybrids were provided to Guinea in 2000 and 2001 for commercial planting.

In 1999, one COGENT-commissioned expert visited Côte d'Ivoire to conduct a pest risk analysis of the ICG-AIO. Two training courses were hosted by the Centre National de Recherche Agronomique (CNRA) in the Côte d'Ivoire up to 2002. Researchers representing 11 countries participated in the training courses. Furthermore, another two local staff underwent IPGRI/COGENT-sponsored staff development training at CIRAD in Montpellier, France on the use of molecular markers (microsatellite kit and associated statistical software), and on cryopreservation. Currently, the application of microsatellite analysis is ongoing at the central biotechnology laboratory of the Centre National de Recherche Agronomique. Leaf samples of important varieties from Ghana will also be collected and analyzed. These activities are funded by IPGRI/COGENT.

Leaf samples of Cameroon Red Dwarf x Rennell Island Tall were provided to CIRAD in France and Max Planck Institute in Germany for coconut map construction, in collaboration with the Mikocheni Agricultural Research Institute in Tanzania (MARI), Philippine Coconut Authority (PCA) and NEIKER in Spain. For this hybrid, agronomic evaluation is being undertaken in Marc Delorme.

About 7200 seednuts of Talls (seven varieties), Dwarf s(nine varieties) and hybrids (seven crossings) were produced by assisted and controlled pollination for Mozambique for coconut seedgarden establishment. For germplasm exchanging, the Coconut Research Institute of Sri Lanka is sending a research team to Marc Delorme Station in August 2004 to bring embryos of three varieties (Nawasi Tall, King coconut and Ran Thambili) to the ICG-AIO. In return, embryos of seven varieties will be collected from ICG-AIO and brought to Sri Lanka for conservation.

Proposal for the establishment of the International Coconut Genebank for Latin America and the Caribbean (Brazil)

EA Tupinamba

Coconut Researcher, Centro de Pesquisa Agropecuaria dos Tabuleiros Costreiros - Empresa Brasileira de Pesquisa Agropecuaria, Aracaju, Sergipe, Brazil

During the COGENT Steering Committee meeting in November 1998, the representative of Empresa Brasileira de Pesquisa Agropecuaria (EMPRAPA) presented Brazil's proposal to host the International Coconut Genebank for Latin America and the Caribbean (ICG-LAC). Subsequently, a site suitability and pest risk assessment survey was undertaken in April 1999 to evaluate the suitability and pest risk of the ICG if situated in Itaporanga, west of Aracaju; the Neopolis plateau, northeast of Aracaju; and Betume, located between Neopolis and Ilha das Flores. Due to ownership problems, the Neopolis Plateau was dropped as a prospective site. Likewise, due to distance problem, the Betume Station was also not found suitable. Thus, the Itaporanga station was subsequently identified as the proposed site for the ICG- LAC.

Itaporanga is 20 km from the city of Aracaju, located 10° 55′ South Latitude and 37° 03′ West longitude, with an elevation of only one meter above sea level. Its predominant soil is ferric with good drainage. The climate is generally warm with the temperatureof the coldest month higher than 15°C. The average annual rainfall is 1643 mm. The area is flat and about 100 ha is available for establishing Tall accessions. Additional areas to plant additional accessions should be identified.

In 1999, COGENT commissioned one expert to go to Brazil to conduct a pest risk analysis of the proposed site of the ICG-LAC. Two local staff were sponsored by COGENT to attend staff development training course on the use of the standardized techniques in coconut breeding (STANTECH), microsatellite kit (molecular marker), dedicated statistical software, technical writing/ seminar presentation and proposal writing. Several meetings and communications were conducted between EMBRAPA and COGENT to discuss issues related to the hosting of the ICG-LAC which includes the issues of derivatives, compliance to Brazil's legislation on intellectual property rights and funding. Embrapa has finally agreed to host the ICG-LAC and the Memorandum of Agreement will be signed soon.

Annex 1.1. MOA for the establishment of the International Coconut Genebank for the South Pacific

AGREEMENT BETWEEN THE GOVERNMENT OF PAPUA NEW GUINEA, THE INTERNATIONAL PLANT GENETIC RESOURCES INSTITUTE (IPGRI) AND THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO) PLACING COCONUT GERMPLASM COLLECTIONS UNDER THE AUSPICES OF FAO

PREAMBLE

The Government of Papua New Guinea (hereinafter referred to as 'Host Country'), hosting the International Coconut Genebank for the South Pacific, the International Plant Genetic Resource Institute (hereinafter referred to as 'IPGRI', one of the Centres of the Consultative Group on International Agricultural Research), acting on behalf of the International Coconut Genetic Resources Network (COGENT), as described in the attachment 'Background to the Agreements') and the Food and Agriculture Organization of the United Nations (hereinafter referred to as 'FAO');

Considering the importance to humanity of protecting and conserving coconut germplasm for future generations;

Considering the International Undertaking on Genetic Resources adopted by the FAO Conference at its 22nd Session in 1983 (Resolution 8/83) and in particular Article 7 thereof; and the Annexes of the Undertaking adopted by the FAO Conference in 1989 and 1991;

Considering that the FAO Commission on Genetic Resources for Food and Agriculture (hereinafter referred to as the "Commission"), as the relevant intergovernmental body in this field, has the responsibility for monitoring the implementation of Article 7 of the International Undertaking on Plant Genetic Resources;

Considering the Memorandum of Understanding Between the Food and Agriculture Organization of the United Nations and the International Board for Plant Genetic Resources (IBPGR) legally succeeded by IPGRI, dated September 21, 1990, on the respective roles of the two organizations in establishing, maintaining and managing germplasm collections and setting standards for these collections;

Considering the importance of the International Coconut Genebank held by the Government of Papua New Guinea within COGENT and supported by IPGRI, as part of a global strategy for germplasm conservation;

Considering that the Coconut germplasm accessions have been donated to the International Coconut Genebank for the South Pacific on the understanding that these accessions will remain freely available;

Considering that any country that so desires may participate in COGENT;

Considering that the Government of Papua New Guinea has expressed the wish that the designated coconut germplasm accessions, kept in the International Coconut Genebank for the South Pacific, be recognized as part of the International Network of Ex *Situ* Collections (as per the International Undertaking on Plant Genetic Resources) under the Auspices of FAO;

- Taking note of the provisions of the Convention on Biological Diversity, particularly those pertaining to affirmation of sovereign rights of nations over their biological resources and access and benefit sharing mechanisms.
- Also taking note of the ongoing process of harmonisation of the International Undertaking on Plant Genetic Resources with the CBD, and the request of the Conference of the Parties to the Convention on Biological Diveristy to the governments to speed up this process.

Have agreed as follows:

Article 1

APPLICATION OF THIS AGREEMENT

This Agreement shall be construed and applied in a manner consistent with the provisions of the Convention on Biological Diversity and the International Undertaking on Plant Genetic Resources.

Article 2

BASIC UNDERTAKING

The Government of Papua New Guinea hereby places under the auspices of FAO, as part of the International Network of *Ex Situ* Collections provided for in Article 7 of the International Undertaking on Plant Genetic Resources, the accessions of coconut genetic resources listed in the Appendix hereto (hereinafter referred to as the "designated germplasm"), in accordance with the terms and conditions set forth in this Agreement. The List of designated germplasm will be updated every two years as new accessions are added to the collection.

Article 3

STATUS OF DESIGNATED GERMPLASM

a) The Government of Papua New Guinea shall hold the designated germplasm in trust for the benefit of all countries in accordance with the International Undertaking on Plant Genetic Resources and the terms and conditions set out in this Agreement.

b) The Government of Papua New Guinea shall not claim legal ownership over the designated germplasm, nor shall it seek any intellectual property rights over that germplasm or related information.

Article 4

PREMISES

a) The premises, i.e., land and/or laboratories, in which the designated germplasm is conserved, shall remain in the charge of the Government of Papua New Guinea.

b) FAO shall have a right of access to the premises at any time and the right to inspect all activities performed therein directly related to the conservation and exchange of the designated germplasm.

Article 5

MANAGEMENT AND ADMINISTRATION

a) The Government of Papua New Guinea undertakes to manage and administer the designated germplasm in accordance with Internationally Accepted Standards, including standards as agreed upon by COGENT, and the International Genebank Standards, endorsed by the Commission, where these are applicable to coconut, and ensuring that all the designated germplasm is duplicated in order to ensure its safety.

b) FAO may recommend action, if it considers such action to be desirable, to ensure the proper conservation of the designated germplasm.

c) If the orderly maintenance of the designated germplasm is impeded or threatened by an event, including *force majeure*, and the Government of Papua New Guinea does not have the capacity to take appropriate preventive or curative action, FAO and IPGRI shall seek the necessary resources from the international community for action to ensure the safety of the designated germplasm, including if necessary by its evacuation and transfer.

Article 6

POLICIES

The Government of Papua New Guinea and IPGRI recognize the intergovernmental authority of FAO and its Commission in setting policies for the International Network of *Ex Situ* Collections referred to in Article 7 of the International Undertaking and undertake to consult with FAO and its Commission on proposed policy changes related to the conservation of, or accessibility to, the designated germplasm, subject, always to the provisions of Article 9 hereinafter. The Government of Papua New Guinea and IPGRI shall give full consideration to any policy changes proposed by the Commission.

Article 7

STAFF

a) Staff responsible to manage and administer the designated germplasm shall be employed and remunerated by the Government of Papua New Guinea.

b) As and when deemed appropriate, FAO and IPGRI shall furnish technical backstopping on request by the Government of Papua New Guinea and COGENT.

Article 8

FINANCES

The Government of Papua New Guinea shall remain responsible for financing the maintenance of the designated germplasm.

Article 9

AVAILABILITY OF DESIGNATED GERMPLASM AND RELATED INFORMATION

Subject to the provisions of Article 10 below, the Government of Papua New Guinea undertakes to make samples of the designated germplasm and related information available directly to all countries participating in COGENT, for the purpose of scientific research, plant breeding or genetic resource conservation, without restriction.

Article 10

TRANSFER OF DESIGNATED GERMPLASM AND RELATED INFORMATION

Where samples of the designated germplasm and/ or related information are transferred to any other person or institution the Government of Papua New Guinea shall ensure that such other person or institution, and any further entity receiving samples of the designated germplasm from such person or institution, is bound by the conditions set out in Article 3 (b) and, in the case of samples duplicated for safety purposes, to the provisions of Article 5 (a).

This provision shall not apply to the repatriation of germplasm to the country that provided such germplasm.

Article 11

DURATION

a) This Agreement is concluded for a period of 4 years and shall be automatically renewed for further periods of 4 years unless notice of non-renewal is given in writing by either party not less than 2 years before the end of any 4-year period.

b) This Agreement shall be revised, if necessary, in accordance with the provisions of the revised International Undertaking.

Article 12

TERMINATION

a) Either FAO or the Government of Papua New Guinea may terminate this Agreement at any time by giving notice to the other, two years in advance of the termination date.

b) FAO, the Government of Papua New Guinea and IPGRI, shall, in such case, take all necessary measures to wind up joint activities in an appropriate manner and, within the limits of their respective competencies, to ensure the continued conservation of and access to the designated germplasm.

Article 13

SETTLEMENT OF DISPUTES

a) Any dispute concerning the implementation of this Agreement shall be settled by mutual consent.
b) Failing mutual consent, such dispute may be submitted, at the request of either FAO, or the Government of Papua New Guinea or IPGRI, to an arbitral tribunal composed of four members. Each party shall appoint one arbitrator. The three arbitrators thus appointed shall designate by mutual consent the fourth arbitrator, who will act as the presiding arbitrator of the tribunal. In case of equal division of votes the presiding arbitrator will have a second vote.
c) If within two months after the receipt of a party's notification of the appointment of an arbitrator one or both of the other parties has/have not notified the first party of the arbitrators they have appointed, the first party may request the Secretary-General of the United Nations to appoint arbitrators to represent parties that have not appointed an arbitrator.
d) If within two months after the appointment of the three arbitrators they have not agreed on the choice of the presiding arbitrator, such presiding arbitrator shall be designated by the Secretary-General of the United Nations at the request of either party.
e) Unless the parties to the dispute decide otherwise, the tribunal shall determine its own procedure.
f) A majority vote of the arbitrators shall be sufficient to reach a decision which shall be final and binding for the parties to the dispute.

Article 14

AMENDMENT

a) FAO, the Government of Papua New Guinea or IPGRI may propose that the Agreement be amended by so informing the other parties
b) If there is mutual agreement in respect of a proposed amendment, the amendment shall enter into force on whatever date is set, and be reported to the next session of the Commission.

Article 15

DEPOSITARY

The Director-General of FAO shall be the Depositary of this Agreement. The Depository shall:

a) Send certified copies of this Agreement to the Member Nations of FAO and to any other Government which so requests;
b) Arrange for the registration of this Agreement, upon its entry into force, with the Secretariat of the United Nations in accordance with Article 102 of the Charter of the United Nations;
c) Inform FAO Member Nations of:
   i) The signature of this Agreement in accordance with Article 16; and
   ii) The adoption of amendments to this Agreement in accordance with Article 14.

Article 16

COMING INTO FORCE

This Agreement shall come into force upon signature by the authorized representative of FAO, the Government of Papua New Guinea and IPGRI.

The Food and Agtriculture
Organization of the United Nations

By: **DAVID A. HARCHARIK**
(Signature)

Date:

The Government of Papua New Guinea

Hon. Tukape Masane, M.P.
Minister of Agriculture and Livestock

By: ______________________________

Date:

The International Plant Genetic Resources Institute (IPGRI)

By: **GEOFFREY HAWTIN**
(Signature)

Date:

Appendix 1

List of germplasm accessions covered by this Agreement

Accessions	Source	Accessions	Source
	East New Britain	31. Saiho	**Oro**
1. Pellavarua	- Gazelle Peninsula	32. Ajoa	
2. Raulawat		33. Kikibator	
3. Natava		34. Siagara	**Milne Bay**
4. New Massava		35. Bubuleta	
5. Natava Many		36. Baibara	**Central**
6. Fruited		37. Hisihu	
7. Gaungo	**West New Britain**	38. Poligolo	
8. Naviro		39. Miha Kavava	**Gulf** -Vailala
9. Talasea Red		40. Keakea	
	New Ireland	41. Iokea	- Iokea
10. Karu village	- Namatanai		
11. Kenapit		42. Severimabu	**Western** (Kiwai Tall)
12. Sohu		43. Boze	
13. Etalat	- Mussau Is.		**Exotic Talls**
14. Lawes	**Manus**	44. Rennell	- Rennell Tall
15. Lako			
16. Baluan		45. PNG Yellow	**Local Dwarfs**
17. Wutung	**Sandaun**	46. PNG Red 1	
18. Hawain	**East Sepik**	47. PNG Red 2	
19. Yangoru		48. Rabaul Red	
20. Vokio		49. PNG Brown	
21. Marineberg		50. Iokea Red	
22. Guanaga	**Madang** (Karkar Tall)	51. Malayan Yellow	**Exotic Dwarfs**
23. Kinim		52. Malayan Red	
24. Ulatava		53. Nias Green	
	Morobe	54. Nias Yellow	
25. Markham Farm	- Markham Tall	55. Nias Red	
26. Liara village			
	East New Britain		
27. Raulawat Yellow	- Gazelle Peninsula		
28. Raulawat Red			
29. Natava Yellow			
30. Natava Red			

Additional list of international germplasm to be established

	Ecotype	Source
56.	Rotuma Tall	Fiji
57.	Tonga Tall	Tonga
58.	Kiribati Tall	Kiribati
59.	Rangiroa Tall	Tahiti
60.	Vanuatu Tall	Ivory Coast, PNG
61.	Western Samoan Tall	Western Samoa
62.	Samoan Yellow Dwarf	Western Samoa
63.	Nui Leka Green Dwarf	Fiji
64.	Fiji Tall	Fiji
65.	Niu Vai	Western Samoa
66.	Niu Afa	Western Samoa
67.	Christmas Is. Tall	Kiribati
68.	Kiribati Green Dwarf	Kiribati
69.	New Caledonia Tall	New Caledonia
70.	Vanikoro Tall	Solomon Island
71.	Solomon Tall	Solomon Island
72.	Niu-bubu, or Pine or Mami Kokonas	PNG & Solomon Islands
	Other Ecotypes	
73.	Cameroon Red Dwarf	Ivory Coast
74.	Salak Green Dwarf	Indonesia
75.	Pilipog Green Dwarf	Philippines
76.	Tacunan Green Dwarf	Philippines
77.	Aromatic Green Dwarf	Thailand
78.	Catigan Green Dwarf	Philippines
79.	Brizilian Green Dwarf	Ivory Coast
80.	West African Tall	Ivory Coast
81.	Sri Lankan Tall	Sri Lanka
82.	Panama Tall	Jamaica

Locations where materials are held:

- **1 – 55** Stewart Research Station; Papua New Guinea Cocoa & Coconut Research Institute Madang, Madang Province
- **56 – 82** To be established at Stewart Research Station, Madang, PNG

Appendix 2

Background to the agreements

The Coconut Genetic Resources Network (COGENT) was established in 1992 to improve coconut production on a substantial basis and to increase incomes in developing countries through improved cultivation of the coconut and efficient utilization of its products. COGENT is actively undertaking an international collaborative programme with member countries to improve the conservation and use of coconut genetic resources in the following areas:

1) Establishing and maintaining an International Database on existing and future collections;
2) Encouraging the protection and utilization of existing germplasm collections;
3) Identifying and securing additional threatened diversity through the development and adoption of suitable technologies and conservation strategies;
4) Promotion of greater collaboration among research groups in producer countries and advanced technology sources in the exchange of germplasm and the development of new techniques; and
5) Appropriate training, information dissemination and securing the necessary funding.

COGENT operates through a steering committee comprised of two members from each of the five sub-networks namely Southeast Asia, South Asia, Pacific, Africa and Latin America/Caribbean, and a full time coordinator based in the Asia, Pacific and Oceania Regional Office of the International Plant Genetic Resources Institute (IPGRI-APO) in Serdang, Malaysia.

COGENT's membership has now grown to 38 coconut-producing countries, with each country having to agree to provide access to its coconut germplasm and data as one of the conditions for membership. The member countries are shown in the table below.

Southeast and East Asia	South Asia	South Pacific	Africa/Indian Ocean	Latin America/ Caribbean
1. China	1. Bangladesh	1. Cooke Islands	1. Benin	1. Brazil
2. Indonesia	2. India	2. Fiji	2.Cote d'Ivoire	2. Colombia
3. Malaysia	3. Pakistan	3. Kiribati	3. Ghana	3. Costa Rica
4. Myanmar	4. Sri Lanka	4. Papua New Guinea	4. Kenya	4. Cuba
5. Philippines		5.Solomon Islands	5. Madagascar	5. Guyana
6. Thailand		6. Tonga	6. Mozambique	6. Haiti
7. Vietnam		7. Vanuatu	7. Nigeria	7. Honduras
		8. Samoa	8. Seychelles	8. Jamaica
			9. Tanzania	9. Mexico
				10.Trinidad-Tobago

Under the mandate of the CGIAR, the IPGRI established COGENT with the endorsement of the Technical Advisory Committee. IPGRI functions as the executing institution for COGENT and provides administration and technical support and advice.

An essential component for sustainable production and improvement in coconut is the availability of a wide diversity of germplasm from around the world for use as introductions or in coconut breeding programmes to develop improved coconut varieties and hybrids for coconut producing countries.

To further ensure the security of germplasm in national collections which are important to each region and to provide member countries with germplasm for developing better varieties and hybrids, COGENT will establish **an international multi-site genebank** consisting of a regional genebank in each of the five COGENT regions. The host country will benefit from the use of the entire germplasm collection, and duplicates supplied from the other regional genebanks, in its breeding programme to develop high-yielding and adapted coconut varieties. The host countries have agreed to a 10-point criterion which includes, among others, access of member countries to the held germplasm and commitment to gather and submit data and to maintain the collection.

The Convention on Biological Diversity (CBD) is a legally binding international agreement that sets out the sovereign rights of countries over their genetic resources as well as the responsibilities of states to conserve and to share these resources and benefits arising from their use.

The Food and Agriculture Organization (FAO) is in the process of establishing Global Network of *Ex Situ* Collections. In December 1994, close to half a million germplasm accessions of food crops held by 12 International Agricultural Research Centres under the CGIAR were placed under FAO trusteeship through a series of agreements signed by FAO and the chairman of the CGIAR acting on behalf of each of the 12 Centres. These agreements were developed in accordance with the CBD.

During a COGENT workshop held on 26-28 February 1996 at Pekanbaru, Riau, Indonesia, representatives of IPGRI, CIRAD and World Bank participated with COGENT members in developing a series of legal agreements, seven-year workplans and proposed budgets for each of the initial four genebanks to be hosted by India for South Asia, Indonesia for Southeast Asia, Papua New Guinea for the Pacific and Côte d'Ivoire for Africa.

The following three agreements, which are considered consistent with the CBD and necessary to facilitate access to coconut genetic resources of which individual countries agree to designate to the international genebanks, are enclosed. These agreements follow closely those agreed to by FAO and the CGIAR centres, with two important changes. First, each host country holding the designated accessions is to be a party in signing the tripartite agreement, and IPGRI is the second party, acting on behalf of COGENT.

(a) The tripartite agreement [Agreement between {Name of Host Country}, the International Plant Genetic Resources Institute (IPGRI) and the Food and Agriculture Organization of the United Nations (FAO) Placing Coconut Germplasm Collections under the Auspices of FAO], provides a list of designated accessions for each genebank, and spells out the rights and obligations of the parties to the agreement.

(b) The Germplasm Acquisition Agreement sets out the terms and conditions of movement of coconut germplasm accessions from the providing country to each of the international genebanks.

(c) A standard Material Transfer Agreement (MTA) specifies that the recipient agrees not to claim legal ownership over the designated germplasm or take out any intellectual property rights over that germplasm or related information. Furthermore, the recipient also undertakes to pass the same obligations to all future recipients of designated germplasm. The MTA will be used for designated germplasm.

Annex 1.2 List of designated germplasm for the International Coconut Genebank for the South Pacific

	Accessions	Source		Accessions	Source
		East New Britain	31.	Saiho	**Oro**
1.	Pellavarua	- Gazelle Peninsula	32.	Ajoa	
2.	Raulawat		33.	Kikibator	
3.	Natava		34.	Siagara	**Milne Bay**
4.	New Massava		35.	Bubuleta	
5.	Natava Many		36.	Baibara	**Central**
6.	Fruited		37.	Hisihu	
7.	Gaungo	**West New Britain**	38.	Poligolo	
8.	Naviro		39.	Miha Kavava	**Gulf** -Vailala
9.	Talasea Red		40.	Keakea	
		New Ireland	41.	Iokea	- Iokea
10.	Karu village	- Namatanai			
11.	Kenapit		42.	Severimabu	**Western** (Kiwai Tall)
12.	Sohu		43.	Boze	
13.	Etalat	- Mussau Is.			**Exotic Talls**
14.	Lawes	**Manus**	44.	Rennell	- Rennell Tall
15.	Lako				
16.	Baluan		45.	PNG Yellow	**Local Dwarfs**
17.	Wutung	**Sandaun**	46.	PNG Red 1	
18.	Hawain	**East Sepik**	47.	PNG Red 2	
19.	Yangoru		48.	Rabaul Red	
20.	Vokio		49.	PNG Brown	
21.	Marineberg		50.	Iokea Red	
22.	Guanaga	**Madang** (Karkar Tall)	51.	Malayan Yellow	**Exotic Dwarfs**
23.	Kinim		52.	Malayan Red	
24.	Ulatava		53.	Nias Green	
		Morobe	54.	Nias Yellow	
25.	Markham Farm	- Markham Tall	55.	Nias Red	
26.	Liara village				
		East New Britain			
27.	Raulawat Yellow	- Gazelle Peninsula			
28.	Raulawat Red				
29.	Natava Yellow				
30.	Natava Red				

Additional list of international germplasm to be established

Ecotype	Source	Other Ecotypes	Source
56. Rotuma Tall	Fiji	73. Cameroon Red Dwarf	Ivory Coast
57. Tonga Tall	Tonga	74. Salak Green Dwarf	Indonesia
58. Kiribati Tall	Kiribati	75. Pilipog Green Dwarf	Philippines
59. Rangiroa Tall	Tahiti	76. Tacunan Green Dwarf	Philippines
60. Vanuatu Tall	Ivory Coast, PNG	77. Aromatic Green Dwarf	Thailand
61. Western Samoan Tall	Western Samoa	78. Catigan Green Dwarf	Philippines
62. Samoan Yellow Dwarf	Western Samoa	79. Brizilian Green Dwarf	Ivory Coast
63. Nui Leka Green Dwarf	Fiji	80. West African Tall	Ivory Coast
64. Fiji Tall	Fiji	81. Sri Lankan Tall	Sri Lanka
65. Niu Vai	Western Samoa	82. Panama Tall	Jamaica
66. Niu Afa	Western Samoa		
67. Christmas Is. Tall	Kiribati		
68. Kiribati Green Dwarf	Kiribati		
69. New Caledonia Tall	New Caledonia		
70. Vanikoro Tall	Solomon Island		
71. Solomon Tall	Solomon Island		
72. Niu-bubu, or Pine or Mami Kokonas	PNG & Solomon Islands		

Note:
Locations where materials are held:

- **1 – 55** Stewart Research Station; Papua New Guinea Cocoa & Coconut Research Institute Madang, Madang Province
- **56 – 82** To be established at Stewart Research Station, Madang, PNG

Annex 1.3 List of designated germplasm for the International Coconut Genebank for South Asia

KASARAGOD

1. Borneo
2. Standard Kudat
3. Java
4. Malayan Orange Dwarf
5. Malayan Green Dwarf
6. F.M.S.
7. S.S. Green
8. S.S . Apricot
9. Philippines Lono
10. San Ramon
11. Cochin China
12. Lifou Tall
13. British Solomon Islands
14. Jamaica Sanblas
15. St. Vincent
16. Blanchissuse
17. Kenya Tall
18. Camaroon Dwarf
19. West African Tall
20. Mawa Hybrid (PB 121
21. Zanzibar Tall
22. Ceylon Tall
23. King Coconut
24. Kappadam
25. Spicata
26. Ayiramkachi
27. Kulasekharam Green Dwarf
28. Kulasekharam Yellow Dwarf
29. Kulasekharam Orange Dwarf
30. Calangute
31. Nadora Tall
32. Andaman Giant
33. Andaman Ranguchan
33. Car Nicobar
34. Auck Chung
35. Tamaloo
36. Kimos
37. Kimmai
38. Katchal
39. Campbell Bay
40. Lakshdweep Micro

KIDU

1. West Coast Tall
2. Andaman Ordinary
3. Benaulim
4. Tiptur Tall
5. East Coast Tall
6. Chowghat Green Dwarf
7. Malayan Yellow Dwarf
8. Philippines Ordinary

Annex 1.4 List of designated germplasm for the International Coconut Genebank for Southeast and East Asia

	Cultivars	Code	Source
1	Malayan Tall	MLT	Malaysia
2	Malayan Yellow Dwarf	MYD	Malaysia
3	Malayan Red Dwarf	MRD	Malaysia
4	Malayan Green Dwarf	MGD	Malaysia
5	Eo Brown Dwarf	EOD	Vietnam
6	Xiem Green Dwarf	XGD	Vietnam
7	Tam Quan Yellow Dwarf	TYD	Vietnam
8	Ta Tall	TAAT	Vietnam
9	Dau Tall	DAUT	Vietnam
10	Bung Tall (Bi Tall)	BIT	Vietnam
11	Giay Tall	GIT	Vietnam
12	Pluak Wan (Edible husk)	PKWT	Thailand
13	Pak Chok Tall	PCKT	Thailand
14	Maphrao So Tall	SOXT	Thailand
15	Kalok Thailand Tall	KLKT	Thailand
16	Thalai Roi Thailand Tall	TLRT	Thailand
17	Nalike Dwarf	NKED	Thailand
18	Maphrao Fai	FAID	Thailand
19	Bali Tall	BAT	Indonesia
20	Tenga Tall	TAT	Indonesia
21	Palu Tall	PUT	Indonesia
22	Sawarna Tall	SAT	Indonesia
23	Riau Tall	RUT	Indonesia
24	Mapanget Tall	MTT	Indonesia
25	Takome Tall	TET	Indonesia
26	Nias Yellow Dwarf	NYD	Indonesia
27	Bali Yellow Dwarf	BYD	Indonesia
28	Bali Green Dwarf	BYD	Indonesia
29	Jombang Green Dwarf	JGD	Indonesia
30	Sagerat Orange Dwarf	SOD	Indonesia
31	Salak Green Dwarf	SGD	Indonesia
32	Raja Brown Dwarf	RBD	Indonesia
33	Tagnanan Tall	TAGT	Philippines
34	Macapuno Tall	MACT	Philippines
35	Laguna Tall	LAGT	Philippines
36	Baybay Tall	BAYT	Philippines
37	Bago-Oshiro Tall	BAOT	Philippines
38	San Ramon Tall	SNRT	Philippines
39	Catigan Green Dwarf	CATD	Philippines
40	Pilipog Green Dwarf	PILD	Philippines
41	Aromatic Dwarf	AROD	Thailand
42	Hainan Tall	HAT	China

43	Cambodia tall	KAT	Côte d'Ivoire
44	West African Tall	W AT	Indonesia
45	Rennel Island Tall	RIT	Indonesia
46	Cameroon Red Dwarf	CRD	Indonesia
47	Tahiti Tall	TAT	Indonesia
48	Panama TaII	PNT	Côte d'Ivoire
49	Niu Leka Dwarf	NLAD	Côte d'Ivoire
50	Vanuatu Tall	VTT	Côte d'Ivoire
51	Indian West Coast Tall	WCT	India
52	Sri Lanka Tall	SLT	Sri Lanka

Annex 1.5 List of designated germplasm for the International Coconut Genebank for Africa and Indian Ocean

	Cultivars	Code	Source
1.	Andaman Giant Tall	AGT	India
2.	Andaman Ordinary Tall	ADOT	India
3.	Baybay Tall	BAYT	Philippines
4.	Cambodia Battambang Tall	KAT09	Cambodia
5.	Cambodia Koh Rong Tall	KAT10	Cambodia
6.	Cambodia Ream Tall	KAT07	Cambodia
7.	Cambodia Sre Cham Tall	KAT08	Cambodia
8.	Cambodia Tuk Sap Tall	KAT02	Cameroon
9.	Cameroon Kribi Tall	CKT	Cameroon
10.	Cameroon Red Dwarf	CRD	Cameroon
11.	Catigan Green Dwarf	CATD	Philippines
12.	Comoro Moheli Tall	CMT	Comoro
13.	Equatorial Guinea Green Dwarf	EGD	Equatorial Guinea
14.	Gazelle Peninsula Tall	GPT	Papua New Guinea
15.	Kappadam Tall	KPDT	India
16.	Karkar Tall	KKT	Papua New Guinea
17.	Kinabalan Green Dwarf	KIND	Philippines
18.	Laccadive Micro Tall	LMT	India
19.	Laccadive Ordinary Tall	LCT	India
20.	Madang Brown Dwarf	MBD	Papua New Guinea
21.	Malayan Green Dwarf	MGD	Malaysia
22.	Malayan Red Dwarf	MRD	Malaysia
23.	Malayan Tall	MLT	Malaysia
24.	Malayan Yellow Dwarf	MYD	Malaysia
25.	Markham Valley Tall	MVT	Papua New Guinea
26.	Mozambique Tall	MZT	Mozambique
27.	Niu Leka Dwarf	NLAD	Fiji
28.	Palu Tall	PUT	Indonesia
29.	Pilipog Green Dwarf	PILD	Philippines
30.	Rangiroa Tall	RGT	French Polynesia
31.	Rennell Island Tall	RIT	Solomon Islands
32.	Rotuman Tall	RTMT	Fiji
33.	Solomon Island Tall	SIT	Solomon
34.	Sri Lanka Green Dwarf	PGD	Sri Lanka
35.	Sri Lanka Tall Ambakelle	SLT02	Sri Lanka
36.	Tacunan Green Dwarf	TACD	Philippines
37.	Tagnanan Tall	TAGT	Philippines
38.	Tahitian Red Dwarf	TRD	French Polynesia
39.	Tahitian Tall	TAT	French Polynesia
40.	Takome Tall	TKT	Indonesia
41.	Tenga Tall	TGT	Indonesia
42.	Ternate Brown Dwarf	TBD	Indonesia

43. Thailand Green Dwarf	THD	Thailand
44. Thailand Tall Ko Samui	THT04	Thailand
45. Thailand Tall Sawi	THT01	Thailand
46. Tonga Tall	TONT	Tonga
47. West African Tall Akabo	WAT03	Côte d'Ivoire
48. West African Tall Mensah	WAT04	Côte d'Ivoire
49. West African Tall Quidah	WAT06	Benin

Status of cryopreservation research in coconut

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Introduction

Seeds cannot be used for coconut germplasm conservation owing to their large size and their highly recalcitrant storage behaviour (Chin and Roberts 1980), which renders their storage under conventional dry and low-temperature conditions impossible. Genetic resources of coconut are thus traditionally maintained in field genebanks. There are many field collections of coconuts in various countries, usually connected with coconut research institutes, which conserve a total of 1416 accessions. This number is projected to increase over the next few years, with the establishment of the multi-site International Coconut Genebank or ICG (see preceding article) under the coordination of the International Coconut Genetic Resources Network (COGENT).

In some ways, field genebanks offer a satisfactory approach to conservation. The genetic resources under conservation can be readily accessed and observed, permitting detailed evaluation. However, there are certain drawbacks that limit their efficiency and threaten their security (Withers and Engels 1990). The genetic resources are exposed to pests, diseases and other natural hazards such as drought, weather damage, human error and vandalism. Nor are they in a condition that is readily conducive to germplasm exchange. Field genebanks are costly to maintain and, as a consequence, are prone to economic decisions that may limit the level of replication of accessions, the quality of maintenance and even their very survival in times of economic stringency. Even under the best circumstances, field genebanks require considerable inputs in the form of land, labour, management and materials (see article on 'Coconut field genebank' in this chapter).

It is now well recognized that the efficient and cost-effective conservation of any given genepool can be achieved only through the implementation of a complementary conservation strategy integrating *in situ* and *ex situ* approaches and utilizing relevant storage methods (Maxted *et al*. 1997). In this context, *in vitro* culture techniques have great potential for the collecting, exchange and conservation of plant germplasm, especially for problem plant species, i.e. those with recalcitrant seeds and those that are propagated vegetatively (Engelmann 1997; 2000). Tissue culture systems allow propagation of plants with high multiplication rates in an aseptic environment. Virus-free plants can be obtained through meristem culture and thermotherapy, thus ensuring the production of disease-free stocks and simplifying quarantine procedures for the international exchange of germplasm. The miniaturization of explants allows genebank managers to reduce space requirements and consequently, the labour costs for the maintenance of germplasm collections. For long-term conservation, cryopreservation, i.e. conservation at ultra-low temperature, usually immersion in liquid nitrogen (-196^{o}C), is the only method currently available for problem species. Cryopreservation protocols have been developed for a wide range of plant species, an increasing number of which are from the tropics (Engelmann and Takagi 2000).

In the case of coconut, in *vitro* culture of zygotic embryos is now routinely applied in numerous laboratories in the framework of germplasm collecting and exchange activities (Batugal and Engelmann 1998; Engelmann *et al*. 2002). This paper summarizes the present status of coconut cryopreservation research.

Status of cryopreservation research

In the case of coconut, only a limited amount of research has been conducted towards the development of cryopreservation protocols, involving research teams in Malaysia, Côte d'Ivoire, France and the UK. Cryopreservation experiments have been performed with zygotic embryos, plumules and pollen. Chin *et al*. (1989) first reported the survival of one single coconut embryo 15 months after freezing using a classical protocol (cryoprotection with DMSO + slow freezing). Assy-Bah *et al*. (1992a,b) reported high recovery of frozen embryos using the pregrowth/ desiccation technique. In the UK, Hornung *et al*. (2001) obtained callus growth from plumules of one coconut variety after cryopreservation using an encapsulation/dehydration protocol, including preculture of encapsulated plumules for 72-96 h in medium with 0.75 M sucrose followed by desiccation with silica gel to around 30% moisture content and rapid freezing. Research on cryopreservation of plumules using the encapsulation-dehydration and vitrification techniques has also been initiated in France (Malaurie *et al*. 2002b). Finally, preliminary unpublished experiments performed in Côte d'Ivoire by the late Béatrice Assy-Bah showed that coconut pollen is amenable to cryopreservation after partial desiccation.

Immature embryos

Experiments were performed with immature embryos sampled from seednuts of the hybrid PB121 (Malaysian Yellow Dwarf x West African Tall) 7 to 8 months after pollination (Assy-Bah and Engelmann 1992a). It was decided to start working with immature embryos, on the assumption that they would be more likely to withstand cryopreservation than mature ones, owing to their smaller size and lower degree of differentiation (Engelmann 1992).

For cryopreservation, embryos were placed for 4 h on pretreatment medium containing 600 g L^{-1} glucose and glycerol, sorbitol or polyethyleneglycol (PEG) 6000 at various concentrations and then immersed directly in liquid nitrogen. After rapid thawing in a water-bath at 40°C, embryos were cultured on standard medium (Assy-Bah *et al*. 1989) for recovery.

After one month, the survival of non-cryopreserved embryos was high for all preculture conditions tested, ranging from 73 to 100%. In the case of cryopreserved embryos, lower survival, ranging between 10 and 43%, was obtained when glycerol at 5 or 10% or sorbitol at 10% was used in the preculture medium. However, numerous abnormalities were observed in the further development of non-cryopserved and cryopreserved embryos, and only few fully developed, normal plantlets could be obtained. This was because conditions for their *in vitro* culture were not mastered (Engelmann and Assy-Bah 1992).

Mature embryos

Experiments were performed with mature embryos sampled from the seednuts of the hybrid PB121; Cameroon Red Dwarf (CRD); Rennell Tall (RT); and Indian Tall (IT), 10 to 12 months after pollination (Assy-Bah and Engelmann 1992b).

For cryopreservation, embryos were placed in open Petri dishes without culture medium and dehydrated for 4 h in the air current of the laminar flow cabinet at room temperature. They were then transferred to open Petri dishes with the medium employed for pretreatment of immature embryos containing 600 g L^{-1} glucose and 15% glycerol (Assy-Bah and Engelmann 1992a), and dehydrated for an additional period of 11 to 20 h. Hence, the total duration of the pretreatment ranged from 15 to 24 h. Embryos were then placed in 2 ml cryotubes and immersed directly in liquid nitrogen. After rapid thawing in a 40°C water-bath, embryos were cultured on standard medium (Assy-Bah *et al*. 1989) for recovery.

The initial moisture content of embryos, which was very similar in all four varieties, averaged 78.4%. It decreased rapidly during the first 15 h of pretreatment to an average of 11.4% and then more slowly, reaching 6.4 % after 24 h. Larger embryos (RT and IT) dehydrated more slowly than smaller ones (PB 121 and CRD).

Survival of non-frozen embryos remained very high (>70 %) after pretreatment. By contrast, no survival was noted after cryopreservation without pretreatment. For varieties with relatively larger embryos (RT, IT and PB 121), survival after cryopreservation increased in line with increasing pretreatment durations, whereas it reached an optimum after 17 h for the variety CRD, which has the smallest embryos. Under optimal pretreatment conditions, survival ranged between 76-100 % with non-frozen embryos and between 73-93 % with cryopreserved ones. Most embryos considered alive after one month germinated and the same proportion of non-cryopreserved and cryopreserved embryos developed into whole plantlets. The main differences between control and cryopreserved embryos were the non-development of the haustorium and a delay of 1 to 2 months in the development of cryopreserved ones.

These results were validated by N'Nan (1997) with embryos of two ecotypes, West African Tall and Malayan Yellow Dwarf, and recently confirmed (N'Nan *et al*. 2003) on a total of 10 ecotypes, including 5 Talls and 5 Dwarfs, originating from Africa, Latin America-Caribbean, South Asia, Southeast Asia and the South Pacific, with 44-100% of cryopreserved embryos giving rise to whole *in vitro* plantlets.

Plumules

Plumules represent a potentially interesting material for cryopreservation because they are of small size (< $1mm^3$), they are mostly composed of meristematic cells and it is possible to regenerate whole plantlets from *in vitro* cultured plumules (Malaurie *et al*. 2002b). Cryopreservation experiments were performed using the encapsulation-dehydration and encapsulation-vitrification techniques.

With the encapsulation-dehydration technique, excised plumules were encapsulated in alginate beads, pregrown for 2-3 days in medium containing 0.5 to 1.0 M sucrose, desiccated to 0.5-0.2 % moisture content and cryopreserved. Depending on the experiments, survival after cryopreservation could reach up to 67%, but only a limited number of frozen plumules could give rise to whole *in vitro* plantlets (Malaurie and Borges 2001; N'Nan *et al*. 2002). Preliminary experiments performed with the encapsulation-vitrification technique (Sakai *et al*. 2000) showed that up to 20% of cryopreserved plumules could survive after freezing

(Malaurie *et al*. 2002a).

Conclusion and prospects

These preliminary results demonstrate the great potential of cryopreservation for the long-term conservation of coconut genetic resources. Additional research has to be performed to further refine and standardize the protocols developed for embryos and plumules, to test the improved protocols with additional genotypes before their large-scale application in the genebank context can be envisaged. Long-term storage of coconut pollen under cryopreservation would represent an important additional technique for allowing conservation of genes. Research is needed to further develop and refine an appropriate technique.

In view of the very positive results described above, it is clear that, in a not too distant future, cryopreservation will play a greater role in the overall approach in the conservation of coconut genetic resources.

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In situ conservation of coconut diversity

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Introduction

Coconut genetic diversity present in farming systems has been maintained through the combined action of natural and human selection and management. Food culture of specific communities also affects selection of preferred culinary traits. In the process of planting, managing, selecting seednuts, harvesting and marketing- farmers, in turn, make decisions on their crops that affect the genetic diversity of the crop populations. Over time, a farmer may alter the genetic structure of a crop population by selecting for plants with preferred agro-morphological or quality characteristics (Jarvis and Hodgkin 2000). Thus, coconut landraces may be a product of farmer selection as well as farmer breeding (Riley 1996).

Coconut varieties are grown by resource poor farmers around the world for a diversity of uses. Home consumption, local markets, for industrial processing, and medicinal use are only a few. Farmers search for locally adapted coconut cultivars for diverse environmental niches. Many varieties are adapted to particular micro-niches including climatic and edaphic stressed environments. Farmer preferences for specific size, aroma, nut water quality, colour, taste and type also demand diverse coconut varieties. The continued use of landraces contributes to stable food production and income especially in marginal environments where impacts of modern varieties are limited or less effective. The Convention on Biological Diversity (CBD) has recognized the continued maintenance of traditional varieties *in situ* as an essential component of sustainable agricultural development. Diversity of local coconut varieties is the foundation upon which coconut breeding depends for the creation of new varieties and is therefore, a critical aspect of food security for coconut-based economies.

To develop successful conservation approach, knowledge of plant biology is essential. Coconut (*Cocos nucifera* L.) is essentially a tree crop of the humid tropics. It is able to adapt to a wide range of soil and climatic conditions. The natural habitat of coconut is the coastal belt of the tropics where it flourishes in sea-washed littoral sand with constant motion of underground current of water in a saline atmosphere (Khan *et al*. 1994).

It is monoecious with numerous male and female flowers in each spadix. Tall and Dwarf are distinct natural population of the coconut gene pool; Tall coconut trees are usually cross-pollinated and consequently, are usually heterogeneous (Nair and Ratnambal 1994; Iyer and Dhamodran 1994; Batugal and Ramanatha Rao 1998). The inflorescence, 1-2m long, consists of a central rachis, with up to 40 lateral branches, which bear 200-300 male flowers above, opening from the tip of branches downwards, and one or more female flowers at the base which are receptive after the pollen has been shed. Flowering starts at 6-12 years of age for Tall types (Purseglove 1975) and 3-4 years for Dwarf types (Nair and Ratnambal 1994). The male flowers are the first to open, beginning at the top of each branch and proceeding towards the base. After the pollen has been shed in the bud, the female flowers open and remain receptive for 24 hours. The flowers are nectiferous and sweet-scented and visited by a range of pollinators, particularly bees, flies and ants, so that a fair amount of insect pollination is possible. The pollen of coconut is dry and therefore, some wind pollination may also occur. Coconut must be propagated by seednuts and cannot be vegetatively propagated. The first European explorers in Asia and the Pacific found coconuts well established in almost all tropical coastal areas and it is believed that ocean currents carry coconuts, and they become established on open coasts without the aid of human beings. Edmonson (1941) reported that coconuts are capable of germinating after floating in the sea for periods of up to 110 days, during which time they could have travelled 3000 miles in favourable currents. Furthermore, coconut can tolerate saline conditions because of their root structure and is also adapted to high humidity and constant supply of water.

What is in situ *conservation?*

In situ conservation is defined by the CBD (Article 2) as "…the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticates or cultivated species, in the surroundings where they have developed their distinctive properties" (UNCED 1992). The definition of *in situ* conservation used in the CBD encompasses two processes: the conservation of wild species in natural ecosystems or reserves, and the maintenance of crops genetic diversity on-farm. On-farm conservation is generally used to describe the processes by which farmers maintain their traditional crop varieties that they have developed and which they continue to manage and improve. These processes have led to the evolution and adaptation of crops to changing environments and socio economic conditions. For coconut genetic diversity, the maintenance of local coconut cultivars within the traditional farming systems is still little studied and understood.

Why in situ *conservation?*

For the last decades, agricultural scientists have responded to the threat of genetic erosion by developing a worldwide network of genebanks, field genebanks and botanical gardens for conserving the available useful genetic resources *ex situ* (Bommer 1991). Since the establishment of the International Coconut Genetic Resources Network (COGENT) by IPGRI in 1992, a total of 14 coconut field genebanks have been established (IPGRI 2001). COGENT (2000) coordinated the establishment of a multi-site International Coconut Genebank (ICG), an international Coconut Genetic Resources Database (CGRD) and the studies of diversity in coconut traits including drought tolerance, suitability for high-value products and compatibility for intercropping. COGENT has 38 member countries and these countries have agreed to share and exchange germplasm by putting selected national accessions in the multi-site ICGs for Southeast Asia (located in Sikijang, Indonesia), South Asia (Karnataka, India), the South Pacific (Madang, PNG) and Africa (Abidjan, Côte d'lvoire). In India, coconut-breeding programme has been utilizing farmer's varieties to develop hybrids from Dwarf x Tall genotype (Ratnambal and Nair 1998). Understanding of coconut genetic resources and its value in traditional farming systems of Sri Lanka, Indonesia, Vietnam, Philippines, Thailand, Fiji, Vanuatu, Côte d'Ivoire, Benin, Ghana, Tanzania, Mexico, Nigeria and Jamaica has improved significantly over time and mother palm selection of preferred coconut genetic resources is a common feature (Batugal and Ramanatha Rao 1998).

While this form of conservation remains no doubt an important method, it does not conserve the evolutionary process of local adaptation of crops to their environments. *In situ* conservation has the potential to: (1) conserve the evolutionary processes of local adaptation of crops to their environments, (2) conserve diversity at all levels – the ecosystem, the species, and the genetic diversity within species, (3) conserve ecosystem services critical to the functioning of the earth's life-support system, (4) improve the livelihoods for resource-poor farmers through economic and social development, (5) maintain or increase farmers' control over and access to crop genetic resources, (6) ensure farmers' efforts are an integral part of national genetic resources systems and involve farmers directly in developing options for adding benefits of local crop diversity, and (7) link farming community to field genebank for conservation and utilization (Jarvis *et al.* 2000).

Basic information needed to implement* in situ *conservation programme

To implement a coconut *in situ* conservation programme, it is necessary to understand where, when and how *in situ* conservation of the coconut crop will be effective, who will maintain the material, and how the maintained material will benefit the stakeholders. Four types of information are needed to design an effective programme:

- The extent and distribution of the coconut genetic diversity maintained by farmers over space and over time;
- The processes used to maintain the coconut genetic diversity on farm;
- The persons who maintains coconut genetic diversity (custodians of genetic diversity) within the farming communities; and
- The factors (market, non-market, social, environmental) that influence farmer decisions on maintaining traditional coconut varieties.

Information on these topics is needed to develop methods for mainstreaming the use of local crop genetic resources into the agricultural development arena.

Building and implementing on-farm conservation programme

On-farm conservation involves partnerships among individuals and institutions. A project dominated by conservationist may fail to emphasize farmers' livelihoods, while a project dominated by development workers may fail to emphasize conservation. A project without ecologists may neglect the importance of ecosystem services that the crop might be providing (Jarvis *et al*. 2000). Once understanding among institutions, collaborators and farming communities has been reached, existing data, such as descriptor lists, databases of e*x situ* germplasm collections, herbarium collections, published literature in the natural and social sciences should be reviewed, together with unpublished information, including the personal knowledge of local extension and NGOs. Site selection criteria and farmer selection criteria should then be defined followed by the training of local research teams in participatory methods for information collection from the local communities. After site selection, communities need to be sensitized to the aims and objectives of on-farm conservation programme; and sampling scheme for data collection should be formulated. Broadly speaking, the criteria for site selection should be based on the extent of genetic diversity, accessibility and interest of the farmers to continue to grow coconut varieties. Jarvis and colleagues (2000) spelt this out below in more detail.

Ecosystems. It will be important to select sites in diverse agroecosystems preferably with different ecotypes. Traditional coastal home gardens are important ecosystem for on-farm management of farmer-preferred coconut diversity *in situ*. This will increase the chances of conserving genetic diversity, as this may be associated with agroecosystem diversity.

Intra-specific diversity within target species. It is important that the areas selected are grown to different coconut landraces.

Specific adaptations. Efforts should be made while selecting different agroecosystems to select sites with extreme environmental conditions (high soil salinity, cold temperatures, etc) and variation in pests. This will help to include types with specific adaptations.

Genetic erosion. It is better to select sites with less threat of genetic erosion to increase the life of conservation efforts.

Diverse use values. It is possible to ensure conservation of hidden genetic diversity by selecting sites with diverse use values of crops for food and other uses. It is important to note that for many farming communities, a crop is not just a matter of food production but also of investing and maintaining social relations and religious rituals.

Farmers and communities. Farmers' interest and willingness to participate are keys in site selection. This may require preliminary work in community sensitisation on the benefits to farmers of conserving crop varieties. Site selection should also include areas with: socio-cultural and economic diversity; diversity of livelihoods, and importance of target crops for various ways of life; farmers' knowledge and skills in seed selection and exchange; and market opportunities.

Partners. Partners with interest in community empowerment, capacity building and development agenda, and experience in conservation interventions will be beneficial to the programme. Partners with distinct community participation expertise will have comparative advantage in dealing with community. The concept of commodity chain, which allows farmers to use multiple parts of coconut trees, increases the chance of conserving *in situ*. This concept of value addition requires the involvement of a full range of partners from different disciplines, who are not usually involved in agricultural biodiversity research.

Logistics. These would include mainly the accessibility of the site throughout the year and availability of resources. The former is very important for a successful *in situ* conservation programme and is essential in monitoring and sharing of information back to the community.

The existing data should be combined with an exploratory survey using Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA) approaches. The community needs to be sensitized to issues on hand and for this purpose, the use of participatory approach is recommended (Friis-Hansen and Sthapit 2000). The following broad steps are essential for the effective implementation of on-farm conservation programme (Sthapit *et al*. 2000) and may need refinement according to local context:

- Locating coconut diversity, ecosystem and community (e.g. ecogeographic survey);
- Creating (or using existing) institutional framework and participatory planning process;
- Site selection (low cost *in situ* conservation site having both high public as well as farmers' utility value of crop genetic resources);
- Community sensitization and strengthening local capacity;
- Locating coconut diversity and custodians of unique and rare types (e.g. diversity fair);
- Measuring and assessing local coconut diversity in terms of richness, evenness and uniqueness (e.g. consistency on farmer's unit of diversity, molecular markers, genetic indices);
- Understanding the perceived value of coconut diversity (e.g. four square method);
- Monitoring diversity (e.g. community biodiversity register) and sharing information;
- Developing strategy for options of on-farm conservation actions;
- Diversity utilization and monitoring of intervention impacts; and
- Mainstreaming information for development and policy reforms.

A number of participatory tools are developed to implement on-farm conservation activities at local level by the farming community themselves, namely:

- *Local knowledge base:* Understanding of local crop diversity and social networks of germplasm and knowledge flow and storage methods; identify technical gaps and strengthen local seed system;
- *Diversity fair:* Local community can organize this fair for locating diversity and custodians, sensitizing community and policy makers and promoting access of information and materials; and
- *Community biodiversity register* (CBR)*:* Recording inventory of local crop diversity and associated local knowledge, and monitoring the increase and decrease of number of landraces and mo-

dern varieties and their distribution pattern within households (by area) or between households within community.

The above activities will raise awareness on local crop diversity and help to understand the value of local crop diversity. Diversity fair and CBR are a few participatory methods, which can strengthen the local capacity to document taxonomic data and traditional knowledge on crop genetic resources (CGR) with the following specific objectives of:

- Creating awareness and developing sense of community ownership on biodiversity;
- Locating unique, rare and culturally significant cultivars and their custodians;
- Enhancing access of genetic materials and information on local crop diversity;
- Developing options of adding benefits and support biodiversity-based livelihoods;
- Building local capacity for monitoring diversity *in situ* and promoting on-farm management of local crop diversity;
- Making aware on and protecting economically important biowealth against biopiracy.

The successful implementation of CBR will depend upon how the approach could provide direct benefits to farming community. One of the direct benefits is that it may help to establish a network of key households, which maintain rare, unique and rich local crop diversity resulting into a network of planting material to form a decentralized community seed bank.

It is important to focus not only in scientific understanding of the project but also to develop institutional capacity to run internally driven on-farm conservation programmes. The value of such decentralized CBR will be clearer when activities such as diversity kits, Participatory Variety Selection (PVS) and Participatory Plant Breeding (PPB) (Sthapit *et al.* 1996; Sthapit *et al.* 2000; Witcombe *et al.* 1996) are integrated into community-based informal seed management and exchange programme. The PPB and the deployment of diversity kits will strengthen the capacity of the farmers to search, select, maintain and exchange genetic resources for obtaining both genetic and socioeconomic benefits for themselves and for the society.

In situ *conservation and its benefits to the community*

The effective management and conservation of genetic resources on farm takes place where the resources are valued and used to meet the needs of local communities (Jarvis *et al.* 2000). In order for local coconut farming systems to be maintained by farmers, the genetic resources must have some value and/or be competitive to other options a farmer might have. Understanding the contribution of coconut cultivars to livelihoods, nutrition and food culture is needed to formulate plans that will: (i) support local germplasm supply systems, (ii) improve PVS and PPB, (iii) develop new markets for coconut cultivars and plant parts, (iv) promote appropriate conservation value and education, (v) create methodologies for integrating locally adapted coconut cultivars and farmer preferences into development and extension projects, and (vi) advise on appropriate policies that support the management and use of crop diversity in agroecosystems (IPGRI 2001).

Two options were used in adding benefits: the first, on adding benefits through participatory variety selection and plant breeding, seednuts networks and grassroots strengthening; and the second, on adding benefits through public awareness, better processing, marketing, policy incentives, and education in the formal sector (Jarvis *et al.* 1998).

The first option is to seek improved quality, disease resistance, high yield, better taste, ease in harvesting and other preferred traits through breeding; seed networks and modified farming systems. In modern agricultural production systems, Smale and her colleagues (2001) argued that crop genetic resistance to disease can be enhanced by policies that encourage: (1) cultivation of a mosaic of varieties with different genetic mechanisms for combating a pest, (2) cultivation of specific varieties that contain multiple genetic mechanisms for resistance, or (3) continual replacement of varieties in farmers' fields by more recent releases or exchange of farmers' cultivars that carry new genetic sources of resistance. The second option includes adding value to coconut resources so that the demand for the material or some derived product may be increased. These diverse options will emerge when the community, researchers and developmental institutions are directly involved in monitoring local crop diversity using CBR and link with crop improvement, seed and market networks for adding benefits on local resources. If diversity can be more highly valued in the marketplace through the creation of consumer demand for certain products, and farmers can access those markets, their incentives to maintain diversity may be increased.

The concept of commodity chain applies with coconut as the approach is not restricted to increase in productivity alone but rather that crop is considered 'as a whole' in all aspects of a chain (or a system), from its production through its consumption. This concept of value addition adds new dimensions to the traditional agricultural research agenda and it implies the involvement of a full range of new partners, who are not usually involved in agricultural biodiversity research.

Measures to conserve coconut diversity *in situ* include:

- Creation of economic incentives mechanisms (such as identification of new products and markets, increase competitiveness of local cultivars, introduction of supportive policies) and other measures to promote cultivation of diverse local coconut cultivars. IPGRI (2000) has documented at least 12 marketable high-value products and market locations for coconut. They include: tender nuts, palm sugar, desiccated coconut, milk/cream, milk powder, fresh coconut, makapuno coconut dessert, coconut water, nata de coco, coir fibre, fibre dust, shell charcoal and activated carbon. Hence, the goal of *in situ* conservation is to encourage farmers to select and maintain local crop diversity to benefit themselves as well as the community at large. Understanding of local food culture reveals the need for a range of coconut cultivars in home gardens.
- Increase profile of non-monetary benefits, which include increased access to information and technologies arising from the use of exchanged information, enhanced research and development capacity of local institutions, low food cost and materials, public recognition, an improved quality of life through access of natural chemical free foods, public awareness, environmental benefits such as the protection of habitats and ecosystems (Raymond and Flower 2001).
- Strengthening local capacity to document, manage and share information of local diversity for the benefits of the community and individual so that the community has the capacity to develop options for on-farm conservation actions.

All this requires greater collaboration between formal and informal sectors with more benefit-oriented activities. Promising results are emerging from all countries and many methods and approaches have been developed which are compiled now to publish guidelines for on-farm conservation of agrobiodiversity (Jarvis *et al*. 2000). These outputs must be evaluated and monitored in terms of effectiveness and sustainability of coconut genetic resources conservation and utilization.

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Poverty reduction in coconut growing communities: A strategy for coconut *in situ* / on-farm conservation

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Introduction

About 96% of coconuts are grown by smallholders tending four hectares or less of land which many of them do not own. About 85% of the 12 million hectares of coconuts are grown in the Asia Pacific region. Coconut farmers are marginalized: they grow coconut and associated crops in rainfed and often environmentally fragile areas; most live below the poverty line; are resource-poor; considered non-bankable by the credit sector; and they do not have political clout to influence public and private sector policy. Even in many of the large coconut producing countries, research support to this sector is inadequate if not nil.

IPGRI believes that if resource-poor farmers are empowered, they could improve their lives and lift their socioeconomic status over the poverty line. To address the urgent need of empowering poor coconut farmers and helping the long neglected coconut sector, IPGRI requested - and the Asian Development Bank (ADB) awarded - a Regional Technical Assistance (RETA) grant to IPGRI (RETA 6005 for 2000-2004) entitled, 'Developing sustainable coconut-based income-generating technologies in poor rural communities'. IPGRI coordinated the project involving eight national coconut research agencies, three non-governmental organizations (NGOs) and 25 community-based organizations (CBOs) in eight Asia Pacific countries (Bangladesh, India, Sri Lanka, Indonesia, the Philippines, Vietnam, Fiji and Papua New Guinea) as shown in Annex 1.

Objective

The project objective is to develop efficient village-level, income-generating technologies and strategies that are technically feasible, financially viable, socially acceptable and environmentally safe, using COGENT's three-pronged strategy: 1) production and marketing of high-value coconut products from all parts of the coconut – the kernel, husk, shell, wood, water and leaves); 2) intercropping cash and food security crops with coconut and integrating livestock/fodder production; and 3) establishing community-managed nurseries to propagate and sell quality planting materials of farmer-selected local and introduced high-value varieties and conserve them on farm. The project also identified, enhanced and provided access to the five essential capitals (physical, natural, financial, social and human) needed to convert these income generating interventions into sustainable livelihoods. For details about the project framework, see COGENT publication entitled, 'Poverty Reduction in Coconut Growing Communities, Volume I: The Framework and Project Plan'.

Activities

Prior to the release of project funds to IPGRI in May 2002, the UK's Department for International Development (DFID) supported the identification and socioeconomic profiling of 89 coconut growing communities from which 24 communities were chosen as project sites. IPGRI and its partner organizations also organized the project team and technical support groups in each country using IPGRI's and national counterpart funds.

Upon release of the ADB funds, the following activities were conducted:

1. Establishment and strengthening of 25 CBOs to manage the project at the community level. Special emphasis was made on the design of the CBOs to ensure broad access and participation of several categories of stakeholders, including women;
2. Establishment of a microcredit system and provision of initial revolving fund for each of the 25 CBOs;
3. Market surveys to identify marketable products and development of market channels to make such markets sustainable;
4. Development and implementation of farmers' and women's action plans for income-generating activities;
5. Development of training manuals on income-generating technologies and the development of instruments for analysis and promotion of viable technologies;
6. Development of community-managed income-generating coconut seedling nurseries and the documentation, enhancement and conservation of selected and promising local and introduced coconut varieties;
7. Training of coconut farmers, women and village-level entrepreneurs on income-generating technologies;
8. Evaluation of inexpensive village-level oil mills and equipment for producing high-value coconut products;
9. Development and viability testing of the production and marketing

of identified marketable high-value coconut products from the kernel, husk, shell, water, wood and leaves; and promotion of varieties suitable for such high-value coconut products;
10. Pilot production and marketing of high-value products from the coconut's kernel, husk, shell, wood, water and leaves;
11. Development and viability testing of: (a) coconut-based intercropping technologies for enhancing incomes and food security; and (b) livestock and fodder production to boost total farm productivity and nutrition; and
12. Promoting the use of research results through field days and the replication and adoption of resulting viable development interventions by national governments, development organizations and NGOs.

The project inception and stakeholders' meeting was held on 25 February – 1 March 2002 in Ho Chi Minh City, Vietnam, hosted by the Oil Plants Institute (OPI); the second project meeting on 20 – 24 August 2003 in Davao City, Philippines, hosted by the Philippine Coconut Authority; and the final project meeting on 27–30 September 2004 in Ho Chi Minh City, Vietnam, and hosted by OPI once more. For details of the project activities and target outputs, please refer to Annex 2 and the COGENT publication entitled, 'Poverty Reduction in Coconut Growing Communities, Volume II: Mobilizing for Action'.

Project outputs

The results of the project proved that poor coconut farmers' and socioeconomically disadvantaged women's lives could be improved if they were properly trained, empowered and given access to opportunities and resources, in this case the coconut-based village-level income generating activities, technologies and related support systems. In a period of only three years, 25 farmer CBOs in eight countries with a total of 5715 members were established and strengthened; 17 392 farmers and women trained on various income-generating activities; 43 community-managed coconut and 14 multi-purpose seedling nurseries established; 65 501 coconut seednuts of local varieties sown in community-managed nurseries; 64 521 coconut seedlings of farmers' and introduced high-value varieties planted and conserved on-farm; 1593 farmers and women involved in coconut-based livestock production trials, 4039 in intercropping trials and 2005 in production of high-value coconut products; and about 140 public awareness materials developed and disseminated. For details of these achievements, please see Annex 3.

In the production of high-value coconut products, more than 2000

CBO members, 74% of whom are women, participated. There were 210 participants in Bangladesh, 17 in Fiji, 615 in India, 100 in Indonesia, 89 in Papua New Guinea, 378 in the Philippines, 168 in Sri Lanka and 428 in Vietnam. CBO members, trained and working as individuals or in groups, produced cooking oil, virgin coconut oil for body and hair lotion, kernel-based detergent and bath soaps, fibre-based ropes, doormats and geotextile, shell- and wood-based cooking utensils and exportable handicrafts, coconut water- and sap-based vinegar and sugar, and coconut leaf-based decorative baskets, hats and other handicrafts. Depending on how many capable members of the participating families were involved, they increased their income by 3-5 times compared to their previous income from copra, securing for them a steady source of additional income and helping them rise above the poverty line. Equally important, this project intervention has provided employment opportunities to formerly unemployed and underemployed rural women resulting in enhanced self-esteem, and economic and social empowerment.

For intercropping, 4039 farmers and their households participated in intercropping trials consisting of 115 in Bangladesh, 454 in Fiji, 759 in India, 748 in Indonesia, 418 in Papua New Guinea, 473 in the Philippines, 328 in Sri Lanka, and 744 in Vietnam. Net incomes from planting cash crops in small plots of land between coconuts have significantly increased. Not only were income and total farm productivity enhanced, but also food security and nutrition since families planted, grew and ate their own produce.

For animal production, a total of 1593 CBO members, 58% of whom are women, raised a variety of livestock like quails, poultry, ducks, rabbits, goats, swine and cattle. There were 185 participants in Bangladesh, 32 in Fiji, 370 in India, 82 in Indonesia, 126 in Papua New Guinea, 334 in the Philippines, 197 in Sri Lanka and 267 in Vietnam. The integration of livestock production in coconut farming is still in its early stages, but many CBO members have already adopted the animal production technologies introduced by the project as components of their sustainable livelihood activities. The initial results showed tremendous potential not only in generating income but more so in improving nutrition.

To support the conservation and promotion of coconut diversity, 43 community-managed coconut and 14 multi-purpose seedling nurseries were established; 65 501 coconut seednuts of local varieties sown in these nurseries; and 64 521 coconut seedlings of farmers' and introduced high-value varieties planted and conserved on farm. The 24 communities (excluding the Maitum site in the Philippines) also identified and characterized 89 important local varieties through farmers' diversity fairs.

Through this participatory intervention, the farmers themselves characterized and identified suitable, high-yielding and high-value local varieties. The source palms of the selected varieties were paint-marked and the seednuts harvested from these palms were propagated in the nurseries. These community-managed nurseries are envisioned to provide a steady supply of high-quality planting materials for the communities.

Project benefits

To determine the benefits and the initial impact of the project, a two-stage assessment was carried out: (1) rapid assessment survey involving project leaders and heads of implementing research agencies, NGOs and CBOs; and (2) more detailed survey involving farmers and other members of the participating communities in the project. Based on these surveys, the following project benefits were identified:

1. The project provided an effective IARC-NARS-CBO mechanism for promoting income generating activities in previously resource-poor coconut growing communities in their countries; and in providing the five needed capitals for sustainable livelihoods (i.e., physical, natural, financial, social and human capitals) to make these income generating activities sustainable. Most of these technologies and resources were not available to the 25 project participating communities in eight countries before the project;
2. The project provided farmers access to efficient but affordable village-level coconut processing equipment, machinery and technologies for producing high-value coconut products which were sourced from several COGENT member countries. In some communities, the local government provided the needed infrastructure and other facilities such as roads, training centres and electrical power connections to support the project;
3. The project enriched the communities' natural capital in the form of important local coconut varieties which farmers identified and characterized with the help of researchers and breeders and propagated them in community-managed nurseries. The project also facilitated the introduction of high-value coconut varieties in the community thereby enhancing the diversity of their coconut germplasm;
4. The project enhanced the communities' social capital by organizing the farmers into CBOs and strengthening and enabling these organizations to effectively plan, manage and implement income generating activities for its constituents;
5. The project provided the needed financial capital in the form of

collateral-free revolving funds for the 25 CBOs to establish their own microcredit systems, enabling poor farmers and women without land or assets to engage in income generating activities; and

6. The project enhanced the human capital of the communities, empowering them through training to effectively and efficiently carry out coconut-based sustainable livelihood activities. The project trained over 17 000 community members on establishing and managing CBOs and microcredit system, producing high-value coconut products, intercropping cash and food security intercrops, raising livestock in a coconut-based farming system and producing feed/ fodder, and establishing and managing seedling nurseries.

Project impact

The same surveys indicated how the benefits generated by the project affected the lives of coconut farmers, particularly their socioeconomic status. The identified initial impacts of the project include:

Impact on farm households

At the farm household level, income generating skills have been enhanced, providing capable members of the family the opportunity to earn in each of the four stages of the commodity chain - production, processing, marketing and consumption– thereby increasing farm incomes by three to five-fold compared to pre-project earnings. And because of additional incomes and savings, more families were able to send their children to school. Intercropping cooking banana, cassava, sweet potato, taro, yams, maize, etc has enhanced food security, while raising vegetables and livestock (native chicken for meat and eggs, goat and cattle for meat and milk, ducks, etc) has improved nutrition. Engaging in collective work has also promoted family cohesiveness.

Impact on communities

At the community level, the impact on women has been particularly tremendous. The project enabled previously destitute and unemployed or underemployed women to earn money, shed inhibitions and empowered them to make informed decisions affecting their lives and, in the process, raising their self-esteem. Unemployment rate in the communities was significantly reduced as formerly idle labour was put into productive use in various coconut-based income generating activities. The project also encouraged community members to work in groups as agricultural entrepreneurs, developing their business and group problem solving skills.

The project also increased farmers' capabilities in optimally and profitably managing their coconut farms, with many adopting the modern, integrated coconut farming systems technique introduced by the project and discarding their traditional methods which mainly revolved around coconut monoculture. Due to the actual socioeconomic benefits experienced by project participants in a period of three years, the project has enhanced the attractiveness of coconut as a commercial crop and has convinced farmers to plant and invest more in coconuts.

The project also increased the awareness of community members on the importance and the need to conserve and promote diversity which is imperative for sustained farm productivity. Because of its unique combination of poverty reduction interventions, the project attracted the attention and, therefore, the support of government, donors and other stakeholders which benefited the participating communities. Its strategic public awareness strategy made popular the participating communities, so much so that others are looking up to them as models of how farmers, working in unison towards a common goal, would be able to make a significant difference in their own lives. Because of the participatory approaches adopted by the project, the farmers' sense of ownership and community belonging were enhanced. The project not only improved the quality of life of resource-poor farmers in coconut growing communities but also prepared them socially, psychologically and emotionally for longer-term socioeconomic development.

Impact on NARS

The survey respondents agreed that the project was able to enhance the service capacity of the research implementing agencies in each of the eight countries. The project improved the 'bridging' or facilitating role of the implementing research institute by providing their scientists, researchers and extension workers with the opportunity to test and disseminate to resource-poor coconut growing communities recommended technologies produced by their research programmes. This has given the implementing agencies' staff the needed exposure to actual grassroots work and boost their confidence about their research. Some project leaders also said that because of the various training and other capacity-building activities conducted under the project, many of their staff acquired new knowledge and skills, thereby "making them better scientists and researchers".

The establishment of community-managed nurseries enabled the research institutes to conserve important local and introduced high-value coconut varieties and promote their *in situ* and on-farm conservation efforts. Also, the establishment and effective management of village-level seedling nurseries, as demonstrated by the communities, could lessen the burden on the part of the NARS and the government in establishing and maintaining a formal seed and seedling distribution system. If replicated and scaled-up, this activity could help provide the framework for establishing a community-managed informal seed distribution system which is self-sustaining – a system in which the communities themselves raise and propagate high-value and suitable varieties, providing the necessary inputs, manpower and land while gaining income from them as well. This could free up the NARS and the government from providing the needed staff and other resources for this purpose and instead realign them into other research areas that would benefit the poor coconut farmers.

Strong linkages between government research institutions and poor coconut growing communities have been established, effectively mobilizing the former to help the latter. This has motivated government researchers to deploy more research results, enhance and expand their coconut-based farming systems research, and link with other relevant research and development organizations.

As a result of the three years of research at the village level, CBO members are now more cooperative with and trusting of government organizations to help them. For the government coconut research institutions, this project has given them an important experience and impetus for developing a research agenda to refine and scale up similarly designed poverty reduction research in coconut growing communities in the future.

Impact on the coconut industry

As the project was implemented in only three to four communities per country, the impact on the industry would not really be obvious at this stage. However, potential impacts have been recognized.

The project demonstrated that diverse high-value products can be made from all parts of the coconut (kernel, husk, shell, wood, water, leaves) and that these could be marketed, thereby expanding the value of coconut as a commodity crop and enhancing the competitiveness of its value-added products in the global market. This could expand existing local and international markets and create demand for new products. This diversity of products that can be profitably produced by farmers at the village level serves as an attractive incentive for them to plant more coconuts, thereby making coconut production and marketing more equitable and sustainable.

In conclusion, this farmer participatory poverty reduction project has shown that poor coconut farmers could effectively manage their coconut and associated production systems to improve their lives. The project has also shown in eight participating countries and other member countries of COGENT that the coconut could be conserved and at the same time optimally utilized to help improve the socioeconomic and environmental conditions of poor rural coconut-growing communities and countries. Based on the results of this project, IPGRI and COGENT will convince and help these countries institutionalize and scale-up this poverty reduction research intervention to maximize its benefits and expand its impact.

Sustainability

Sustaining impact when a project phases out is a major concern especially of those dealing with action research for development, in this case, reducing poverty through the introduction and testing of various coconut-based income-generating technologies. Under the project, this concern was consciously addressed by adopting and integrating into its design the sustainable livelihoods framework, which essentially calls for identifying and implementing interventions to enhance the five capitals (i.e., human, natural, social, physical and financial) as well as formulating sustainability indicators for each intervention.

Human capital

In the project, human capital was enhanced through the conduct of various training and capacity-building activities aimed at two essential objectives: (1) to organize farmers into formal CBOs and strengthen these organizations so that they would be able to effectively manage their own affairs without the help of 'outsiders' even after the project terminates; and (2) to build the capacity and skills of individual farmers to undertake various income-generating activities to enable them to fully and profitably engage in coconut-based enterprises in the future. Of course, building-up the capacity of CBOs and its members through training is just one aspect of enhancing human capital to ensure the sustainability of project impact. Another equally important aspect is giving farmers a sense of self-confidence, self-realization and fulfillment, which goes hand-in-hand with training to tap into their potentials and develop their skills, which the project helped achieve. Once these values are ingrained in them, they would have the motivation and the spirit to continue to further develop themselves and thereby contribute to the development of the community in general.

Natural capital

It is an accepted fact that in order for the benefits and impact of this project to endure long after it has terminated, the component central to its strategy (i.e., coconut diversity) will have to be continuously enhanced. Thus, the project has established a mechanism through community-managed seedling nurseries that would assure the continuous on-farm propagation of high-value and suitable coconut varieties. Catering to both coconuts and various other intercrops, these integrated nurseries would form the platform on which a self-sustaining, non-government dependent, informal and village-level seed and seedling distribution system could be built on. Such a system, which would benefit both the farmers – as they would also earn from them – and the government – they would free scarce resources needed to maintain such nurseries – would ensure that coconut diversity, as well as the diversity of various cash, food security and feed crops, in the communities would continue to improve and flourish.

Social capital

The whole gamut of people, tradition and culture comprise what we call a community's 'social fabric'. In the implementation of the project, the enhancement of the social capital was taken into account by introducing activities and technologies that are socially acceptable – those that do not run counter to the existing norms of the people and the community. This ensures that no friction is created between the project interventions and the people who were supposed to adopt them. In Huntu, for example, a predominantly Muslim project site in Indonesia, swine was not introduced as livestock despite market surveys showing that pork has a high demand in the neighbouring villages as this is in conflict with the dominant religion in the area. Efforts like this would ensure that interventions introduced would continue to be supported by the community.

Under the project, individual farmers were encouraged to form common-interest groups in undertaking similar income-generating activities, which promoted social cohesiveness and group unity. In the coconut fibre processing community of Tam Quan Nam in Vietnam, for example, CBO members established a common area for dehusking, decorticating and collecting fibre. Each member of the group takes turns in operating and maintaining the machinery and the work area itself, and as 'payment' they get processed coconut fibre which they then bring home to use in producing ropes, mats, geotextile and other fibre-based products. These are then collected and sold by the CBO on behalf of its members, with part of the proceeds going to the further upkeep of the machinery and equipment. Such a practice ensures that that machinery and the processing area are well-kept, which would have been very difficult if only the CBO did the job itself. This has proven to be so successful that they are now constructing another building (shed) to house one more set of fibre processing machinery, even after the project has phased out in December 2004.

Additionally, there was conscious effort that technologies introduced by the project would be simple enough that all the members of the family would be able to take part in them. In raising poultry under coconut for example, young children could feed the chickens before going to school and after classes. In making single-ply fibre ropes, the technology is so uncomplicated that even the grandparents could learn how to spin coconut fibre, and the machine is very simple and inexpensive that a family could own two or more units. In all, the project interventions and activities promoted unified family work and bound the family closer together with the common objective of contributing to the upliftment of their plight. Social cohesiveness is vital if continuous community development is to be achieved.

Physical capital

It goes without saying that infrastructure, machinery, equipment and other physical facilities are important in a technology-based poverty reduction project such as this. Under the project, the physical capital of the communities was enhanced by introducing simple, inexpensive, village-level machinery and equipment to process coconuts into high-value, marketable products. This was a strategy adopted by the project to ensure that successful technologies would easily be replicated, adapted and expanded by the communities themselves at minimal cost but with maximum benefit to its constituents, even when the project ended.

The project also promoted the interchange of technologies between and among countries. The Vietnam model of the simple single-ply rope making machine could now be seen in other countries which participated in the project and who did not have this machine before. Another example is the simple coconut virgin oil extracting machine of Sri Lanka, which has been disseminated to other countries as well. Some of these technologies and machines, shared in good faith by countries, have been modified and adapted to suit the local conditions of the communities, usually through the initiative of the CBOs themselves and with some support from the national implementing agencies. These simple but highly efficient and effective technologies, machinery and equipment would provide the motivation for the communities and the farmers to continue to adopt them since they provide additional income at minimum cost –

an almost no lose situation for them. To protect the interest of the inventors or developers of these village-level machineries and equipment, a Material Transfer Agreement which binds recipients not to patent these resources has been developed by IPGRI-COGENT.

Also, because of the project's achievements, the local government units have taken notice of the project sites that some of them provided the needed infrastructure to support their development. Some have given diesel-powered generators to run the dehusking and decorticating machinery provided by the project, while others have improved the farm to market roads going in and out of the project sites to help farmers transport their products. Others have also promised to install transformers to provide three-phase electrical line to a project site so that the CBO members could cheaply operate coconut processing machinery which presently runs on a diesel generator. These physical and infrastructure improvements would go a long way in making sure that the project's interventions and impact would continue.

Financial capital

One of the main reasons why small-scale coconut farmers remain poor is because they have very limited access to financial resources to diversify and invest in higher-return, high-value income generating activities or enterprises. As mentioned, most coconut farmers are marginalized – with no land and collateral to obtain loans and are considered non-bankable by formal lending institutions. This is also the reason why most 'relief' or dole-out projects fail – farmers have a very simple concept of money - when you have it, you spend it, without consideration of paying it back since it was 'given'. Although the project provided funds to the communities, these were mostly in the form of revolving funds for microcredit that the CBO used to loan-out to members which were repaid at nominal interest. At the onset of the project, the CBOs were told that "nothing is free in this project", that everything would have to be paid back, except training and capacity building. With this principle in mind, the CBOs were encouraged to develop their own microcredit lending system, which would make their revolving fund grow. The establishment of these microcredit systems provided the 'non-bankable' farmers access to capital which they used to finance their various coconut-based income-generating activities. This initiative proved successful that some CBOs have doubled or almost tripled the original seed money given to them by the project. Moreover, the microcredit system inculcated in the farmers a sense of 'pay back' – meaning they have to work to repay what they owe and not merely spend their money at whim. Such a system would ensure that farmers have continuous access to needed financial resources to further expand their activities and at the same time catalyze the fiscal growth of the CBO to serve more poor members.

Lessons learned

The lessons learned from the Poverty Reduction project were consolidated from the various communications, correspondences and meetings with the Country Project Leaders, Community Coordinators and project participants; and from the reports submitted, and discussions with other project staff and stakeholders, including partners and collaborators in the project sites. Some of the lessons are not entirely new, and many cut across various topics. There are 33 lesson points, which are listed below and classified under eight major headings:

On implementing the project

1. A special arrangement to expedite the transmittal and release of funds from the Implementing Agencies (IA) to the CBOs was necessary for more efficient project implementation;
2. Staff assigned to the project should have been freed of some of their regular institutional workload so that they could have focused more on implementing and monitoring the activities of the project;
3. Formalizing the assignment of staff to the project (i.e., Programme Leader, the Project Leader, Community Coordinators and members of the Technical Support Team), indicating terms of reference, duties, responsibilities and obligations, would have helped mitigate the delays and difficulties caused by unexpected staff movement;
4. Having a senior staff of the IA as head of the Project Management Team (i.e., Programme Leader) was advantageous in terms of project implementation and team coordination; and
5. A comprehensive and exhaustive orientation and levelling off to get a clear grasp of the nature, concept, rationale, strategy, objectives and overall goal of the project could have prevented the confusion as to the true nature of the project that was evident among some project implementers and participants.

On transferring coconut-based income-generating technologies through on farm and off farm trials

6. Different people had different but equally valid reasons and motivations for choosing to be involved or not to be involved in certain project-related activities; therefore, not all people tried all the technologies being tested or introduced or, conversely, not all technologies introduced suited all project participants. The reasons

and motivations of farmers for testing and adopting or not adopting project interventions need to be further identified and studied;

7. Testing and introduction of improved livestock breeds, specifically of poultry, did not always translate to immediate adoption of the technology by farmers as the latter have a different set of criteria than researchers or scientists in selecting the poultry type they would adopt;
8. Exchange visits were effective mechanisms in promoting and disseminating various coconut-based income generating technologies and in catalyzing in-country and international partnerships and collaboration;
9. Making people fully understand the purpose and advantages of forming focused groups and letting them do so at their own choice and pace was better than 'forcing' them to establish or join a group just for the sake of meeting the project's requirements but not really understanding why; and
10. A 'blue print' project design was not always suitable or applicable to different communities in different countries with highly-diverse peoples and distinct cultures.

On managing community-based organizations

11. The success of the CBO, as with any other organization, hinged much on the leadership qualities and dedication of its officers;
12. Since the project both strengthened CBOs in areas where one already existed and established new CBOs in communities where there was none before, it was recognized that the former was more advantageous in terms of producing more results given the activities and time frame of the project; and
13. The CBO, to continue to effectively function as a social organization, also needed to earn income to sustain itself.

On monitoring and evaluating the project

14. Designing a project Monitoring and Evaluation (M&E) system and its tools without the inputs or participation of those who were supposed to regularly implement them, especially Project Leaders and Community Coordinators, was ill-advised as monitoring and reporting became unfocused;
15. Limited, and oftentimes difficult, accessibility to some of the project sites posed some challenges to project implementation, monitoring and evaluation;
16. The country project leader and project support/ technical team should be physically located as near as possible to each other and the project sites;

17. The project Community Coordinators should be located in the same community where the project is being implemented;
18. Project IA staff (other than the Community Coordinators) should be extensively immersed in the field to get the "feel" of the community and to earn the trust and respect of its members; and
19. Documenting project success stories and lessons are effective approaches in highlighting critical changes in the participants' lives, in rallying support for the communities and in learning from past mistakes and successes to make the future, and ourselves, better.

On building the capacity of CBO members

20. Purposeful hands-on training is the most effective method to maximize farmer learning;
21. Men and women have different reasons and considerations in joining project activities. Therefore, training requires gender-specific approaches which take into account such differences;
22. Participation in training activities is not always possible for those who live far from the project community proper;
23. Transfer of technologies within the CBO – members training other members – was a long and often arduous process which largely depended on the kind of the technologies to be transferred;
24. Building the organizational management capacity of both IA staff and CBO officers to implement and manage project interventions should have been given top priority; and
25. Linking the project with providers of training and capacity building support services could make capacity building activities sustainable.

On marketing

26. Encouraging and helping farmers diversify into more than one income-generating activity or enterprise was better than persuading them to pursue just one. This not only provides them with more earning options but more importantly, it spreads out the risks in case one activity fails or if the market becomes saturated with one of the products;
27. Poor transport infrastructure (farm-to-market roads) and facilities negate the benefits realized from increased farm productivity; and
28. Linking with specialized associations or organizations dealing with product and market development was a good approach in developing and promoting the products of the CBOs.

On establishing and managing a village-level microcredit system

29. The community microcredit systems that were generally successful usually shared common characteristics, which are: (a) provision of

small, non-collateralized loans in cash or in-kind; (b) flexible repayment in cash or in-kind; and (c) with technical backstopping and training support;

30. Employing people who are well-respected and highly-regarded in the community increased the recovery rate of loans; and
31. An elaborate yet simple screening process for borrowers and applying social pressure to collect payments helped in recovering loans.

On promoting coconut diversity (planting of coconut seedlings)

32. Involving the landowners in communities where most farmers are tenants proved to be beneficial in promoting the diversity of coconuts and other crops; and
33. Land tenure, farm size and perceived benefits were major determining factors in encouraging or discouraging farmers to plant coconut seedlings.

Constraints and recommendations

Constraints

1. The delayed release of donor funds to IPGRI and consequently to the implementing agencies which delayed the overall implementation of the project. This was alleviated by initiating the project using the counterpart funds of IPGRI and the eight participating national research organizations;
2. The replacement of the project leader of the Philippines in the middle of the project and of Fiji close to the end of the project. This was remedied by the accelerated support to the project through the effort of consultants and the Project Coordinator;
3. Reservation of some countries in sharing their coconut processing equipment, machineries and technologies. This was remedied through the development of a Material Transfer Agreement (MTA) binding recipient countries not to acquire patents to transferred equipment and machineries. Interest to share technologies was increased by convincing more countries to also share their processing technologies on a reciprocal basis; and
4. Lack of technical staff from national coconut research organizations to provide adequate technical support to the project. This will be remedied in the future projects by negotiating with the implementing agency to provide this much needed technical support.

Recommendations

1. IPGRI and its partner implementing agencies should regularly monitor the status of project assets which were transferred to the 25 CBOs including their use of the project machineries and revolving funds for income generating activities.
2. The activities in the 25 communities as indicated in item 1 above should be complemented by additional project activities under the newly approved IFAD-funded Technical Assistance Grant to IPGRI entitled 'Overcoming poverty reduction in coconut growing communities' which will involve 15 countries including four of the previous ADB-funded RETA.
3. IPGRI should institutionalize and enhance sustainability elements by linking the communities and research organizations with support groups in the public and private sector.
4. IPGRI should scale up the project by helping countries develop their research agenda on poverty reduction in coconut growing communities and loan-based project proposals in order to develop a critical mass of research to help the neglected coconut sector.

Acknowledgment

IPGRI and COGENT would like to thank the eight NARs organizations, the three NGOs and the 25 CBOs which collaborated with IPGRI to implement the project; IFAD in funding the first initiative which identified initial high-value coconut products and production systems for increasing farmers' incomes; DFID in supporting the identification and socioeconomic profiling of the 25 project sites; and ADB in supporting the large-scale testing of technologies and strategies, empowerment and capacity building and overall management of the project. Last but not least, IPGRI-COGENT would like to thank the over 17 000 poor coconut farmers and socioeconomically disadvantaged women who organized themselves and collaborated with each other to improve their lives.

Annex 1. List of participating national coconut research agencies, non-governmental organizations and community-based organizations in the Poverty Reduction in Coconut Growing Communities Project

National Research Institutes:

1. Bangladesh Agricultural Research Institute (BARI), Bangladesh
2. Central Plantation Crops Research Institute (CPCRI), India
3. Coconut Research Institute (CRI), Sri Lanka
4. Indonesian Center for Estate Crops Research & Development (ICECRD), Indonesia
5. Philippine Coconut Authority (PCA), Philippines
6. Oil Plant Institute of Vietnam (OPI), Vietnam
7. Ministry of Agriculture, Sugar and Land Resettlement (MASLR), Fiji
8. Cocoa and Coconut Institute (CCI), Papua New Guinea

Non-governmental Organizations:

1. Banchte Shekha Foundation, Sri Lanka
2. Peekay Tree Crops Development Foundation, Vayalar, India
3. Siyath Foundation, Sri Lanka

Community-based Organizations:

Bangladesh

1. Bandabila Coconut Community, Bandabila, Jessore District
2. Chandrapara Coconut Community, Chandrapara, Barisal District
3. Banchte Shekha (BS) Coconut Community, Jamira, Khulna District

India

4. Ariyankuppam Community Coconut Farmers' Association, Ariyankuppam
5. Pallikkara Community Coconut Development Centre, Pallikkara
6. Vayalar Community Development Centre, Vayalar, Kerala

Sri Lanka

7. Thuthipiritigama Entrepreneurship Development Society, Thuthipiritigama, Hettipola, Kurunugala, Northwestern Province
8. Womens Savings Effort, Wilpotha, Puttalam, Western Province
9. Dodanduwa Womens Collective, Dodanduwa, Galle, Southern Province

Indonesia
10. Kelompok Tani Kelapa Harapan Wori, Wori, Wori District, Minahasa Regent, North Sulawesi
11. Kelompok Tani Kelapa Momosad Nonapan I, Nonapan, Poigor District, Bolaang Mongondow Regent, North Sulawesi
12. Kelompok Tani Kelapa Huyula Huntu, Huntu-Batudaa, Bongomeme District, Donggala Regent, Gorontalo Province

Philippines
13. Malapad Integrated Livelihood Cooperative, Malapad, Real, Quezon
14. Bahay Patol Agrarian Reform Beneficiaries Multi-Purpose Cooperative, Caliling, Cauayan, Negros Occidental
15. Linabu Coconut Planters' Association, Linabu, Misamis Oriental
16. Fleischer Estate Integrated Marketing Cooperative, Old Poblacion, Maitum, Saranggani (associated CBO)

Vietnam
17. Hung Phong/Phong Nam Coconut Communes, Hung Phong and Phong Nam, Giong Trom District, Ben Tre Province
18. Xuan Dong Coconut Community, Xuan Dong, Tien Giang Province
19. Tam Quan Nam Coconut Community, Tam Quan Nam, Binh Dinh Province

Fiji
20. Tukavesi Development Association, Tukavesi, Savusavu
21. Belego Multiracial Farmers Association, Belego, Wailevo, Savusavu
22. Cicia Women's Group, Cicia Island

Papua New Guinea
23. Murukanam Community Association, Murukanam, Madang Province
24. Transgogol Community Association, Transgogol, Madang Province
25. Last Karkar Community Association, Last Karkar, Madang Province

Annex 2. Summary of activities and target outputs of the eight countries participating in COGENT's Poverty Reduction Project (January 2002 to December 2004)

Project Activities	Target Outputs							
		India						
	Sri Lanka	c/o CPCRI (2 sites)	c/o Peekay Tree (1 site)	Bangladesh	Indonesia	Philippines	Fiji	Papua Ne Guinea
I. Capacity Building								
A. Establishment & strengthening of Community-Based Organizations (CBOs) (CBO incorporated and registered with appropriate government agency)	3 CBOs	2 CBOs	1 CBO	3 CBOs	3 CBOs	3 CBOs	3 CBOs	3 CBOs
B. Training of officers/leaders and members on : (1) CBO management and responsibilities; and (2) Microcredit system and management	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 100 members	Per project site: ▪ 10 officers/ leaders ▪ at least 10 members
C. Identification of marketable products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high value coconut products ▪ 3 crop products ▪ 3 livestock products	Per project site: At least: ▪ 3 high valu coconut products ▪ 3 crop products ▪ 3 livestock products
D. Evaluation of oil extraction machines	Per country: 2 machines	Per country: 2 machines	-	Per country: 2 machines	Per country: 2 machines	Per country: 2 machines	Per country: 2 machines	Per country: 2 machines
E. Evaluation of other processing machines (Each country should evaluate at least 3 of 5 machines for meat, fibre, shell, leaf & wood products)	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery for meat, fibre, shell, leaf or wood product	Per project site: At least 1 machinery f meat, fibre, shell, leaf or wood produc

Project Activities	Target outputs							
	Sri Lanka	India c/o CPCRI (2 sites)	India c/o Peekay Tree (1 site)	Bangladesh	Indonesia	Philippines	Fiji	Papua New Guinea
F. Development of action plans for income-generating activities								
1. Farmers' action plan	1 per project site	1 per project site	1 per project site	1 per project site	1 per project site	1 per project site	1 per project site	1 per project
2. Women's action plan	1 per project site	1 per project site	1 per project site	1 per project site	1 per project site	1 per project site	1 per project site	1 per project
G. Fabrication of selected inexpensive processing machines from (E) above	Per country: 1-3 machines	Per project site: 1-3 machines	Per project site: 1-3 machines	Per country: 1-3 machines	Per country: 1-3 machines	Per country: 1-3 machines	Per country: 1-3 machines	Per country: 1-3 machine
II. Training of Farmers and Women								
A. High-value coconut products	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers and 4 extension workers	Per project si ▪ 100 participants with at leas 20% wome ▪ at least 2 researcher and 4 extension workers
B. Intercropping	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project si ▪ 100 participants with at leas 20% wome ▪ at least 2 researcher 4 extensior workers
C. Livestock production	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project site: ▪ 100 participants with at least 20% women ▪ at least 2 researchers & 4 extension workers	Per project si ▪ 100 participants with at leas 20% wome ▪ at least 2 researcher 4 extensior workers

Project Activities	Target Outputs							
	Sri Lanka	India c/o CPCRI (2 sites)	India c/o Peekay Tree (1 site)	Bangladesh	Indonesia	Philippines	Fiji	Papua Ne Guinea
D. Feed formulation	Per project site: At least 5 farmers trained in item (C) above	Per project site: At least 5 farmers trained in item (C) above	Per project site: At least 5 farmers trained in item (C) above	Per project site: At least 5 farmers trained in item (C) above	Per project site: At least 5 farmers trained in item (C) above	Per project site: At least 5 farmers trained in item (C) above	Per project site: At least 5 farmers trained in item (C) above	Per project si At least 5 farmers train in item (C) above
III. Production and Marketing								
A. Identification, production and marketing of high-value coconut products	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project site: At least 3 different high-value coconut products (one from meat, fibre, shell, leaf or wood)	Per project si At least 3 different high value cocon products (on from meat, fi shell, leaf or wood)
IV. Intercropping Trials								
A. Cash crops	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project site: ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved	Per project si ▪ 3 types of annuals ▪ at least 1 perennial crop ▪ at least 50 farmers involved
B. Food security crops	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project site: ▪ 3 types of crops ▪ at least 50 farmers involved	Per project si ▪ 3 types of crops ▪ at least 50 farmers involved
C. Sourcing and propagation of quality plant materials for intercrops identified in (A) and (B) above	▪ CRISL (for coconut seednuts) ▪ Agrarian services centers	▪ CPCRI ▪ Kerala Agri. University (KAU) ▪ Tamil Nadu Agri. University (TNAU) ▪ State Gov't Centers	▪ Coconut Development Board ▪ CPCRI ▪ Agricultural University Department	▪ BARI ▪ BADC ▪ DAE ▪ Hort Centre	▪ Agricultural University and State Government	▪ PCA	▪ Wainigata Research Station ▪ local extension services compound	▪ PNGCCRI ▪ NARI ▪ DAL

Project Activities	Target Outputs							
	Sri Lanka	India: c/o CPCRI (2 sites)	India: c/o Peekay Tree (1 site)	Bangladesh	Indonesia	Philippines	Fiji	Papua Ne Guinea
V. Livestock								
A. Livestock production	Per project site: 3 types of livestock involving at least 50 farmers	Per project site: 3 types of livestock involving at least 50 farmers	Per project site: 3 types of livestock involving at least 50 farmers	Per project site: 3 types of livestock involving at least 50 farmers	Per project site: 3 types of livestock involving at least 50 farmers	Per project site: 3 types of livestock involving at least 50 farmers	Per project site: 3 types of livestock involving at least 50 farmers	Per project si 3 types of livestock involving at least 50 farmers
B. Pasture, fodder and legumes	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project site: At least 1 type each of pasture, legume & fodder, involving at least 50 farmers	Per project si At least 1 typ each of pasture, legume & fodder, involving at least 50 farmers
C. Local feed formulation by each CBO	Per project site: At least 1 feed formulation per type of livestock	Per project site: At least 1 feed formulation per type of livestock	Per project site: At least 1 feed formulation per type of livestock	Per project site: At least 1 feed formulation per type of livestock	Per project site: At least 1 feed formulation per type of livestock	Per project site: At least 1 feed formulation per type of livestock	Per project site: At least 1 feed formulation per type of livestock	Per project si At least 1 fee formulation p type of livestock
D. Sourcing and multiplication of quality livestock for loan or distribution *Suggestion: CBOs should explore the possibility of linking with appropriate NGOs for this activity*	▪ CRISL ▪ VRISL ▪ Local livestock distribution programmes	▪ KAU ▪ TNAU ▪ State Government Centers	▪ KAU ▪ Animal Husbandry Department ▪ National banks' loan programmes ▪ Nabard	▪ Livestock Research Institute	▪ Livestock State Government Center	▪ DAR cattle dispersal programme	▪ Animal Health & Production Division	▪ Dept. of Ag & Livestock research

Project Activities	Target Outputs							
	Sri Lanka	India: c/o CPCRI (2 sites)	India: c/o Peekay Tree (1 site)	Bangladesh	Indonesia	Philippines	Fiji	Papua Ne Guinea
VI. Conservation and Enhancement of Coconut Diversity								
A. Characterization of existing coconut varieties in each project site using: 1. Farmers' protocol (to be provided by COGENT) 2. STANTECH protocol 3. Molecular markers - COGENT to provide additional budget (except those with asterisk*)	CRISL scientists to characterize coconut varieties in each site	CPCRI scientists to characterize coconut varieties in each site	Survey to be conducted	BARI scientists to characterize coconut varieties in each site using the STANTECH Manual	RICP and CRIEC scientists to characterize coconut varieties in each site	PCA-ZRC to conduct varietal surveys in each site	Taveuni Coconut Center & Wainigata Research Station scientists to characterize coconut varieties in each site *	Survey to be conducted
B. Identification of high-yielding (HY) and high-value (HV) coconut varieties	Per project site: ▪ 3 HY ▪ 2 HV	Per project site: ▪ 3 HY ▪ 2 HV	Per project site: ▪ 3 HY ▪ 2 HV	Per project site: ▪ 3 HY ▪ 2 HV	Per project site: ▪ 3 HY ▪ 2 HV	Per project site: ▪ 3 HY ▪ 2 HV	Per project site: ▪ 3 HY ▪ 2 HV	Per project si ▪ 3 HY ▪ 2 HV
C. Establishment of community-managed nurseries for propagation & sale of: 1 Coconuts 2. Intercrops 3. Pasture/Fodder/ Legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/ fodder/ legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/ fodder/ legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/ fodder/ legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/ fodder/ legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/ fodder/ legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/fodder/ legumes	Per project site: ▪ 2 coconut nurseries ▪ 1 integrated nursery for intercrops and pasture/ fodder/ legumes	Per project si ▪ 2 coconut nurseries ▪ 1 integrate nursery for intercrops and pastur fodder/ legumes
D. Planting of 5 coconut seedlings per year	Per project site per year: 5 seedlings per 100 farmer/ women participants	Per project site per year: 5 seedlings per 100 farmer/ women participants	Per project site per year: 5 seedlings per 100 farmer/ women participants	Per project site per year: 5 seedlings per 100 farmer/ women participants	Per project site per year: 5 seedlings per 100 farmer/ women participants	Per project site per year: 5 seedlings per 100 farmer /women participants	Per project site per year: 5 seedlings per 100 farmer/ women participants	Per project s per year: 5 seedlings p 100 farmer/ women participants
VII. Dissemination and Promotion of Research Results								
A. Development of Techno guides (TGs) / Extension Bulletins (EBs)	Per project site per year: ▪ 3 TGs (in English & national language) ▪ 1 brochure on HVP	Per project site per year: ▪ 6 TGs/EBs relevant languages	Per project site per year: ▪ 3 EBs (local language)	Per project site per year: ▪ 2 TGs (local dialects) ▪ 2 EBs	Per project site per year: ▪ 2 TGs/ EBs (relevant languages/ dialects)	Per project site per year: ▪ 15 TGs (local dialects)	Per project site per year: ▪ 2 TGs/EBs (relevant languages/ dialects)	Per project s per year: ▪ at least 3 TGs/EBs

Project Activities	Target Outputs							
	Sri Lanka	India: c/o CPCRI (2 sites)	India: c/o Peekay Tree (1 site)	Bangladesh	Indonesia	Philippines	Fiji	Papua Ne Guinea
B. Seminar/presentation about project	At least once a year	At least once a year	2 seminars per year	4 seminars per year	At least once a year	At least once a year	At least once a year	At least onc year
C. Publication of scientific paper	At least 1 scientific paper per year	At least 1 scientific paper per year	At least 1 scientific paper per year	At least 1 scientific paper per year	3 scientific papers per year	2 scientific papers per year	3 scientific papers per year	3 scientific papers per year
D. Publication of public awareness materials in the national dailies	At least 2 per year	6 in the local & national dailies per year	3 in the local & national dailies per year	At least 2 per year	6 in the local & national dailies per year	6 in the local & national dailies per year	3 in the national dailies per year	3 in the local national daili per year
E. Field days	At least twice per year per site	At least twice per year per site	At least twice per year per site	At least twice per year per site	At least twice per year per site	At least twice per year per site	At least twice per year per site	At least twic per year per site
VIII. Project Meetings and Site Visits								
A. Meeting of CBO officers/ leaders	Per project site: Once a month with report submitted	Per project site: Once a month with report submitted	Per project site: Once a month with report submitted	Per project site: Once a month with report submitted	Per project site: Once a month with report submitted	Per project site: Once a month with report submitted	Per project site: Once a month with report submitted	Per project si Once a mon with report submitted
B. Meeting of CBO members	Per project site: Once per year with report submitted	Per project site: Once per year with report submitted	Per project site: Once per year with report submitted	Per project site: Once per year with report submitted	Per project site: Once per year with report submitted	Per project site: Once per year with report submitted	Per project site: Once per year with report submitted	Per project si Once per ye with report submitted
C. Site visits by project leader	Per project site: At least once every 2 months	Per project site: At least once every 2 months	Per project site: At least once every 2 months	Per project site: At least once every 2 months	Per project site: At least once every 2 months	Per project site: At least once every 2 months	Per project site: At least once every 2 months	Per project si At least once every 2 mon
D. Group meetings of country project leader and three community coordinators	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a yea (semiannual
E. Meetings of project leader with project technical support team	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a year (semiannual)	Twice a yea (semiannual

Project Activities	Target Outputs							
	Sri Lanka	India		Bangladesh	Indonesia	Philippines	Fiji	Papua Ne Guinea
		c/o CPCRI (2 sites)	c/o Peekay Tree (1 site)					
IX. Reporting								
A. Report of community coordinator to project leader	30th of every month	30th of every month	30th of every month	30th of every month	30th of every month	30th of every month	30th of every month	30th of every month
B. Technical and financial report of project leader to IPGRI	Every year: 15 June and 15 Dec	Every year: 15 June and 15 Dec	Every year: 15 June and 15 Dec	Every year: 15 June and 15 Dec	Every year: 15 June and 15 Dec	Every year: 15 June and 15 Dec	Every year: 15 June and 15 Dec	Every year: 15 June and Dec
C. Integrated donor report of IPGRI to ADB	30th June and 30th December of every project year							
X. Provision of equipment								
A. Computer [1]	1 unit	-	1 unit	1 unit	1 unit	1 unit	1 unit	1 unit
B. Motorcycles [2]	3 units	2 units	-	3 units	3 units	3 units	3 units	3 units

[1]The computer and colour printer are for the exclusive use of the project leaders for official communications/e-mail, report preparations, design and printing of Technoguides/ Extension Bulletins (with coloured cover pages), production of training materials and other public awareness materials and/or for other purposes related to the implementation of the project. If the project leader is changed or replaced, the said equipment must be turned over to his/her replacement.

[2] The motorcycles are intended for the exclusive use of the community coordinators for organizing, monitoring and implementing project activities in their respective project sites. The country coordinators are expected to maintain and use the motorcycle for purposes related to the project only. In case the community coordinator is changed or replaced, the motorcycle should be turned over to his/her replacement.

Annex 3. Summary of achievements of COGENT's Poverty Reduction project (January 2002 - December 2004)

Country and name of community	Name of CBO	No. of members	No. of training participants*	Nurseries established (coconut/ integrated)	Seednuts propagated	Seedlings planted on farm	Farmers involved in livestock trials	Farmers involved in intercropping trials	Farmers involved in high-value products	P awa activ mat pub disse
Bangladesh		**325**	**4980**	**9**	**5100**	**3473**	**185**	**115**	**210**	
• Bandabila, Bagharpara, Jessore	Bandabila Coconut Community	100	1660	3	1700	1152	42	43	60	
• Chandrapara, Babugonj, Barisal	Chandrapara Coconut Community	100	1660	3	1700	571	61	39	50	
• Jamira, Phultalam, Khulna	Banchte Shekha (BS) Coconut Community	125	1660	3	1700	1750	82	33	100	
Fiji		**453**	**1919**	**2**	**1000**	**1257**	**32**	**454**	**17**	
• Tukavesi, Cakaudrove	Tukavesi Development Association	128	553	1	500	461	5	128	-	
• Belego Wailevu	Belego Multiracial Farmers Association	105	456	1	500	596	27	106	12	
• Cicia Island	Cicia Women's Group	220	910	0	0	200	-	220	5	
India		**1692**	**3269**	**15**	**5600**	**8800**	**370**	**759**	**615**	
• Vayalar, Kerala	Vayalar Community Development Project	900	1615	9	2000	7000	230	227	315	
• Ariyankuppam, Pondicherry	Ariyankuppam Commune Coconut Farmers Association	320	925	3	1800	1800	120	60	300	
• Pallikara, Kasaragod	Pallikere Community Coconut Dev. Centre	472	729	3	1800	-	20	472		
Indonesia		**748**	**1009**	**9**	**6727**	**6975**	**82**	**748**	**100**	
• Wori, Wori District, Minahasa Regent	Kelompok Tani Kelapa Harapan Wori	257	328	3	2227	1496	20	257	36	
• Nonapan, Poigor District, Bolaang Mongondow Regent	Kelompok Tani Kelapa Momosad Nonapan I	355	357	3	2500	4289	50	355	23	

Country and name of community	Name of CBO	No. of members	No. of training participants*	Nurseries established (coconut/ integrated)	Seednuts propagated	Seedlings planted on farm	Farmers involved in livestock trials	Farmers involved in intercropping trials	Farmers involved in high-value products	P awa activ mat pub disse
• Huntu, Bongomeme District, Donggala Regent	Kelompok Tani Kelapa Huyula Huntu	136	324	3	2000	1190	12	136	41	
Papua New Guinea		**524**	**358**	**3**	**3000**	**9937**	**126**	**418**	**89**	
• Murukanam, Madang	Barem Community Association	226	171	1	1000	7757	13	120	38	
• Transgogol, Madang	Transgogol Community Association	198	109	1	1000	1180	113	198	30	
• Last Karkar, Madang	Last Karkar Community Association	100	78	1	1000	1000	-	100	21	
Philippines		**740**	**1609**	**5/2**	**27 674**	**22 728**	**334**	**473**	**378**	
• Malapad, Real, Quezon	Malapad Integrated Livelihood Cooperative	145	583	2/0	6589	1610	101	290	123	
• Caliling, Cauayan, Negros Occidental	Bahay Patol ARB (Agrarian Reform Beneficiaries) Multipurpose Cooperative	129	380	1/1	1535	2446	125	71	49	
• Linabu, Balingasag, Misamis Oriental	Linabu Coconut Planters Association	109	386	1/1	16 000	18 672	45	53	125	
• Old Poblacion, Maitum, Saranggani	Fleischer Estate Integrated Marketing Cooperative	357	260	1/0	3550	-	63	59	81	
Sri Lanka		**780**	**1287**	**0/6**	**9900**	**8041**	**197**	**328**	**168**	
• Dodanduwa, Galle District	Dodanduwa Women's Collective	420	410	0/1	3290	910	62	214	62	
• Thuttiripitigama, Hettipola	Thuttiripitigama Entrepreurship Development Society	160	430	0/2	3305	3481	77	63	53	

Country and name of community	Name of CBO	No. of members	No. of training participants*	Nurseries established (coconut/ integrated)	Seednuts propagated	Seedlings planted on farm	Farmers involved in livestock trials	Farmers involved in intercropping trials	Farmers involved in high-value products	P awa activ mat pub disse
• Wilpotha, Puttalam District	Women's Savings Effort	200	447	0/3	3305	3650	58	51	53	
Vietnam		**453**	**2961**	**0/6**	**6500**	**3310**	**267**	**744**	**428**	
• Hung Phong & Phong Nam, Giong Trom, Ben Tre	Hung Phong/Phong Nam Coconut Community	103 100	730 513	0/3 0/2	5000 500	2000 400	102 56	319 238	88 175	
• Xuan Dong, Tien Giang	Xuan Dong Coconut Community	100	321	0		410	72	24		
• Tam Quan Nam, Binh Dinh	Tam Quan Nam Coconut Community	150	1397	0/1	1000	500	37	163	165	
TOTAL for eight countries	**25 CBOs/ farmers' associations**	**5715**	**17 392**	**43/14**	**65 501**	**64 521**	**1593**	**4039**	**2005**	

**Some farmers attended multiple training activities*

***Additional project fact sheets for each community have been disseminated during the field days in February-March 2003 (India - 3, Sri Lanka - 3, Vietnam – 3, Indonesia - 3); also includes media (TV and radio) coverage*

Global coconut conservation strategy

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Introduction

In 1992, at the request of the Consultative Group on International Agricultural Research, the International Coconut Genetic Resources Network (COGENT) was launched by the International Plant Genetic Resources Institute (IPGRI). Starting with 15 countries, COGENT rapidly developed into an active global Network currently involving 38 coconut producing countries (Table 1). The establishment of COGENT paved the way for the global and regional coordination of coconut conservation efforts.. However, with the increasing threat of genetic erosion and the increasing poverty in coconut growing communities, there is a need to further support these initial initiatives of coconut growing countries to upgrade the collections and to enhance and accelerate the documentation, evaluation, conservation and use of coconut genetic resources.

Table 1. COGENT member countries

Southeast and East Asia	South Asia	South Pacific	Africa/Indian Ocean	Latin America/ Caribbean
1. China	1. Bangladesh	1. Cooke Is.	1. Benin	1. Brazil
2. Indonesia	2. India	2. Fiji	2. Cote d'Ivoire	2. Colombia
3. Malaysia	3. Pakistan	3. Kiribati	3. Ghana	3. Costa Rica
4. Myanmar	4. Sri Lanka	4. Papua New Guinea	4. Kenya	4. Cuba
5. Philippines		5. Solomon Is.	5. Madagascar	5. Guyana
6. Thailand		6. Tonga	6. Mozambique	6. Haiti
7. Vietnam		7. Vanuatu	7. Nigeria	7. Honduras
		8. Samoa	8. Seychelles	8. Jamaica
			9. Tanzania	9. Mexico
				10. Trinidad-Tobago

Over the past three years, COGENT has conducted several consultations on the conservation and use of coconut diversity to assist coconut growing member countries to develop a progressive conservation strategy. Such a strategy aims to optimize the conservation of as much representative diversity as possible in the most cost-effective manner for the short, medium and long term. These consultations led to a draft Global Coconut Conservation Strategy. In November 2004, the Global Crop Diversity Trust supported a meeting with of the major coconut producing countries to review and update the strategy and identify priority conservation activities.

The updated strategy was referred to the COGENT Steering Committee, to coconut growing countries and COGENT partner research organizations and, based on the feedbacks received, this revised draft was produced. The strategy will be finalized at the next COGENT Steering Committee meeting in India in November 2006. The resulting Global Coconut Conservation Strategy defines the framework for promoting the effective conservation and use of coconut genetic resources over the next 10 years to guide coconut producing countries in developing their own conservation strategies. This strategy and the identified priority activities are described below.

Integrated approach to coconut conservation

The coconut conservation strategy is anchored in promoting the sustainable protection of diversity and maximizing its use. In developing the conservation strategy, coconut growing countries recognized that no one method of conservation can meet all conservation needs and that there is a need to employ a combination of methods to ensure the sustainable conservation of as much diversity as possible. The strategy encourages the participation of governments, partner organizations in both developing and developed countries, NGOs and coconut farmers themselves.

The components of the conservation strategy are: 1) conservation in national field collections; 2) conservation in the multi-site International Coconut Genebank; 3) *in vitro* embryo culture and cryopreservation; 4) *In situ* and on-farm conservation; 5) Promoting conservation through use by : a) developing and implementing a globally coordinated coconut breeding programme, b) establishing farmer community-managed coconut seedling nurseries in at least 25 countries, c) linking germplasm conservation and use with the broader areas of research and development assigned to CIRAD (agro-physiology and crop protection) and APCC (processing and marketing) by PROCORD; d) developing and disseminating catalogues of conserved germplasm and farmers' varieties; and e) upgrading and wider use of the International Coconut Genetic Resources Database (CGRD).

Scope and status of coconut conservation

Conservation in national field collections

National governments, through their coconut research institutes or their equivalents hold important coconut germplasm collections in their research stations. To date, 22 countries have conserved, characterized and registered their data on a total of 1416 accessions in the International

Coconut Genetic Resources Database (CGRD, Table 2). Gaps in collections in the South Pacific Island countries, especially in the atolls, have been identified in a CIRAD survey, and in the Indian Ocean countries through a CPCRI-India survey. There is a need to enhance collecting and conservation from these climate change-vulnerable island countries to address the threat of genetic erosion due to global warming. There is also a need to identify, collect and conserve germplasm with resistance/ tolerance to the dreaded lethal yellowing disease in Africa and in the LAC region; to the foliar decay disease in Vanuatu; and the cadang-cadang disease in the Philippines. Due to climate change, there is a need to identify, collect and conserve drought-tolerant germplasm, noting that almost all coconuts are grown in rainfed conditions. Finally, there is a need to collect and conserve materials with specific characteristics for coconut product value addition that could produce high-value products for poor coconut farmers.

Conservation in COGENT's multi-site International Coconut Genebank

While national coconut field genebanks are important sources of germplasm for exchange, germplasm exchange among countries has been limited due to political and technical constraints.

To address these constraints, and to foster an efficient and effective system of germplasm exchange and conservation, the COGENT Steering Committee decided to establish a multi-site International Coconut Genebank (ICG) in 1995. The ICG today comprises 4 regional genebanks hosted by Indonesia for Southeast and East Asia, Papua New Guinea for the South Pacific, India for South Asia and Côte d'Ivoire for Africa and the Indian Ocean. Negotiations are underway to establish a 5th regional genebank in Brazil.

The ICG field genebank collections are held in trust under the auspices of FAO. The designated germplasm is shared under the terms of material transfer agreements agreed with FAO. The ICG field genebanks are established, maintained and managed by national programmes with guidance from COGENT and IPGRI. The conservation strategy envisions that the ICG laboratories and facilities will be further developed and upgraded the enable them to further locate representative diversity, identify and eliminate duplicates, conduct disease indexing, process pollen and embryos for export, conduct cryopreservation and train coconut researchers from member countries in evaluating, conserving and using germplasm.

The mandates of the International Coconut Genebank are: 1) to conserve nationally and regionally identified priority diversity; 2) to

Table 2. Documented data on national collections in the CGRD with percentage of passport descriptors (P) and evaluation descriptors (E) and the number with photographs and molecular data)

Site	Number of accessions	E=0	0<E≤25	25<E≤50	50<E≤75	75≤E≤100
CNRA Marc Delorme Research Station, Côte d'Ivoire	99	0	28	28	43	0
Coconut Programme, OPRI, Ghana	16	12	0	4	0	0
CRC Sémé Podji, LOCATION Benin	4	0	0	4	0	0
National Coconut Development Programme, Tanzania	72	0	3	69	0	0
AFRICAN REGION	**191**	**12**	**31**	**105**	**43**	**0**
Centro de Investigacion Cientifica de Yucatan, Mexico	20	0	19	1	0	0
Coconut Industry Board, Jamaica	60	0	2	58	0	0
EMBRAPA, Brazil	16	0	0	16	0	0
LATIN AMERICA-CARIBBEAN REGION	**96**	**0**	**21**	**75**	**0**	**0**
BARI, Bangladesh	40	0	3	3	34	0
Coconut Research Institute, Sri Lanka	78	0	14	51	13	0
CPCRI, India	212	0	1	138	73	0
RS, Pakistan	32	0	32	0	0	0
SOUTH ASIAN REGION	**362**	**0**	**50**	**192**	**120**	**0**
Cocoa and Coconut Research Institute, PNG	3	0	0	3	0	0
Ministry of Agriculture, Tonga	7	0	6	1	0	0
Saraoutou Research Station, Vanuatu	79	0	6	10	1	62
Stewart Research Station, PNG	54	0	0	54	0	0
Taveuni Coconut Centre, Fiji	11	0	4	3	4	0
RS, Western Samoa	9	0	0	9	0	0
RS Yandina, Solomon Islands	21	0	0	21	0	0
SOUTH PACIFIC REGION	**184**	**0**	**16**	**101**	**5**	**62**
RS, China	17	0	0	17	0	0
Department of Agriculture, Sabah Malaysia	45	0	15	30	0	0
MARDI Hilir Perak, Malaysia	44	0	5	2	37	0
Bone Bone Experimental Garden, S. Sulawesi, Indonesia	41	0	0	41	0	0
Mapanget Experimental Garden, N. Sulawesi, Indonesia	74	0	29	45	0	0
Pakuwon Experimental Garden, W. Java, Indonesia	25	0	0	25	0	0
Sikijang Experimental Garden, Indonesia	30	0	0	30	0	0
Philippine Coconut Authority, Philippines	224	0	5	138	81	0
Chumphon Hort. Research Centre, Thailand	52	0	0	52	0	0
Dong Go Experimental Center, /Vietnam	31	0	15	12	4	0
SOUTHEAST ASIAN REGION	**583**	**0**	**69**	**392**	**122**	**0**
TOTAL FOR ALL REGIONS	**1416**	**12**	**187**	**865**	**290**	**62**

conserve internationally identified priority diversity; 3) to further assess the diversity, evaluate the performance of the conserved germplasm and disseminate related information to coconut-producing countries; 4) to make germplasm available to interested coconut-producing countries in accordance with agreed protocols; and 5) to conduct research and training in relation to the above.

By 2010, each ICG plans to conserve a maximum of 200 accessions in the regional field genebanks. The material will be contributed by coconut-producing countries in each region. This number is an estimate of the optimum representation of regional diversity that can be maintained by each host country using its national resources. Care has been taken to ensure that each accession included is unique and is not a duplicate and this is currently being further validated using molecular marker studies Accessions are imported in the form of excised embryos, grown *in vitro* in the embryo culture laboratory, transplanted into the greenhouse and eventually into the field. These accessions, which are planted in the field genebank of about 200 hectares, are characterized and evaluated using morphometric and molecular marker protocols to determine their diversity, performance, and potential for improvement work.

Four types of coconut accessions will be conserved in the ICG: 1) major varieties (parents of existing hybrids and advanced generations of selected cultivars); 2) varieties/cultivars threatened with genetic erosion or total loss; 3) varieties/cultivars with special traits/genetic markers; and 4) genotypes being used for current genetic diversity studies using molecular markers.

Member countries of each region can access germplasm from any of the regional genebanks. The requested accessions will be sent in the form of embryos or pollen after disease indexing to ensure safe movement. To make the ICG hosting sustainable, requesting countries will be charged the cost of producing the seednuts and for preparing the embryos, disease indexing and shipping and a pro-rata cost of maintenance. These germplasm transfers are covered by Material Transfer Agreements which is a provision in all ICG hosting agreements.

Host countries agree to commit resources for the establishment, maintenance, germplasm evaluation and data gathering required for the effective management of the regional genebank. Operational support comes from national and international donors and income generation activities such as the production and marketing of high-value products from all parts of the coconut; intercropping and livestock raising as appropriate

The sites for ICG were chosen based on surveys conducted by coconut experts, who considered and evaluated several important criteria. Thus, the basic needs of field genebanks such as safety and security, accessibility, environment etc. have been considered. Among several items that were considered, two principles were highlighted:

1. First, the importance of having a balance between elite lines and accessions that represent a broad range of genetic diversity from the region as a whole was recognized from the beginning.
2. Second, it was agreed that the nationally important accessions that cannot be accommodated in the regional genebanks, i.e. those which are only important to one or few countries, would be maintained in the national collections of strong national programmes.

Thus, from the beginning it was apparent that national collections and the ICG would complement each other to accommodate as much coconut genetic diversity as possible.

Despite its meagre resources, the ICGs have made some significant achievements. Table 3 shows the date of signing of the hosting agreements and the status of conserved germplasm in each of the host countries.

There is a need to accelerate the full establishment and upgrading of the ICGs to make them more useful to protect germplasm from genetic erosion and to promote wider use of coconut diversity in coconut producing countries. This will require increasing the number of conserved material up to a maximum of 200 accessions in each ICG host country, upgrading and expansion of current embryo culture laboratories, germplasm importation from ICG regional member countries, growing embryos *in vitro*, transplanting resulting seedlings and maintenance in the FGBs. There is also the need to establish the ICG for LAC region in Brazil and to establish the field genebank expansion area for the ICG-SEEA in Indonesia.

Table 3. Germplasm conserved in the multi-site ICG

Name of Genebank	Date of MOA signed	Initial number in list of designated germplasm	Designated germplasm currently conserved
International Coconut Genebank for the South Pacific (Papua New Guinea)	30 September 1998	55	50
International Coconut Genebank for South Asia (India)	30 October 1998	49	46
International Coconut Genebank for Southeast and East Asia (Indonesia)	26 May 1999	52	29
International Coconut Genebank for Africa and The Indian Ocean (Côte d'Ivoire)	14 October 1999	49	99*

** Includes additional accessions entered into the ICG after the signing of the MOA*

In vitro embryo culture and cryopreservation

Although conservation in field genebanks is the most popular and practical method of coconut conservation, the field genebank has several disadvantages: 1) it occupies a large land area; 2) it is labour- and time-intensive; 3) extreme care in labelling and managing fields is necessary; 4) many biotic and abiotic factors impact on the safe conservation of germplasm; 5) as the volume of the planting material is quite large (as either seednuts or seedlings in polybags), it is inconvenient for transportation; 6) exchanging the germplasm internationally is strictly restricted by quarantine and reliable tissue/embryo culture techniques are required for the safe movement of germplasm. Thus, it is necessary to complement field genebanks with other conservation methods and COGENT is developing other methods such as *in vitro* conservation and cryopreservation.

The use of *in vitro* culture techniques, including slow growth and cryopreservation, represents an important additional option for the medium and long-term conservation of species like coconut. Coconut is a species with large seeds with no dormancy. Germination of mature seed (fruit) starts within 2-3 weeks after it drops to the ground or harvested. These two characteristics drastically limit the amount of material which can be gathered during collecting missions. A simple and efficient *in vitro* field collecting technique has been developed which involves extracting the embryos from the nuts and inoculating them directly onto culture medium. Embryos can be kept for two months before transfer to culture in a controlled laboratory environment.

Conventional slow growth protocols are not currently available for coconut due to the difficulties encountered with propagation techniques for this crop. However, short-term conservation of zygotic embryos has been achieved by using culture conditions which delay germination for twelve months. Additional experiments are currently underway to assess the applicability of this technique to a wide range of varieties. Currently, the *in vitro* embryo culture process itself, i.e. from the inoculation of embryos *in vitro* to the production of whole plants ready for transfer *in vivo,* has been refined through a collaborative effort involving 11 partner countries. This has significantly improved the *in vitro* culture step of the whole process, especially recovery rates. However this method still needs further refinement of techniques for collecting in the field and transfer to the lab protocol, and in acclimatization of the resulting plants both *in vitro* and *in vivo*. Finally, additional data are being collected on the development and growth in the field of plants coming from *in vitro* culture.

In vitro techniques have been used extensively for exchanging coconut germplasm in the form of excised embryos inoculated *in vitro*. The FAO/

IBPGR Technical Guidelines for the Safe Movement of Coconut Germplasm recommend that coconut germplasm be distributed in this form to reduce chances of introducing diseased material into disease-free areas and COGENT has been following these guidelines. IPGRI/COGENT has published a Manual on Germplasm Health Management for the International Coconut Genebank which will serve as a guide for ICG and national genebank managers and the quarantine service.

Pollen conservation is another option for coconut germplasm conservation. Pollen can be easily collected and cryopreserved in large quantities, occupying very little space. In addition, exchange of germplasm through pollen poses fewer problems of quarantine than is the case for seed or other propagules. Additional research is needed to further develop and refine an appropriate technique. Once this technique is refined, it can be used as an adjunct to in vitro conservation so that the pollen of in vitro conserved material could be used for coconut improvement purposes, instead of waiting for the regenerants to grow and flower.

The potential of somatic embryogenesis as a tool to promote coconut germplasm conservation and accelerated use has been explored. If successful, it could be used to rapidly multiply identified parent materials to provide adequate numbers of plants for breeding or replanting.. During the last COGENT Steering Committee meeting, it was strongly recommended that more focused research on establishing appropriate protocols for somatic embryogenesis be pursued. Such a technique can aid greatly in coconut germplasm management as well as help in rapid multiplication and mass propagation both for breeding and replanting programmes.

For long-term conservation, preliminary experiments have led to the development of a cryopreservation protocol, which has been successfully applied to zygotic embryos of four different genotypes. Additional work is required to refine the cryopreservation technique and to carry out experiments with additional genotypes. It is envisioned that the ICGs will serve as the repository of cryopreserved germplasm when these are fully capable. However, interim repository arrangements with capable partner institutions such as the Secretariat of the Pacific Commission may be explored.

To ensure efficient safe movement of germplasm, there is a need to improve the coconut embryo culture protocols, in order to increase the recovery of embryo-cultured plants, particularly in the stages of plant acclimatization *in vitro* and *in vivo*. There is also the need to undertake additional research on crypopreservation using different representative varieties to identify suitable plant tissues to be conserved across different accessions.

Two major constraints related to cryopreservation as a long term strategy for coconut conservation are the lack of an efficient regeneration protocol for coconut and the unverified fidelity of genetic materials regenerated from cryopreserved tissues. The future of long term conservation of coconut through cryopreservation would depend on the results these studies. Therefore, there is a need to develop an efficient regeneration protocol using somatic embryogenesis. To further test the efficiency of cryopreservation, there is a need to conduct molecular marker-based analysis of regenerated materials to test their genetic fidelity.

In situ **and on-farm conservation**

About 85% of coconuts are grown in South and Southeast Asia and the effects of farmers' practices in this region on the extent and distribution of genetic diversity are of great importance. It is thus likely that the major part of coconut diversity will remain *in situ*, in the yards or gardens of small farmers, undisturbed tropical sea coasts and uninhabited islands.

Today, many farmers' varieties are in danger of being lost, resulting in genetic erosion of some of the most adapted and needed germplasm for sustainable coconut production. Initial results indicate that the threats to genetic erosion caused by urbanization, shifts to other more profitable crops, calamities such as drought, typhoons, pests and diseases are real and need to be addressed

Sustainable *in situ* conservation will require community participation, control of land rights in local communities, the systematic documentation of farmers' knowledge of coconut diversity, education, extension and development of environmental awareness. Of equal importance is the principle that any *in situ* conservation programme must also benefit local communities. Management by local communities can often develop effective links to national efforts on documentation, conservation and use. This can attract commercial and private agencies to be partners in on-farm conservation efforts and can lead to much wanted linkages between public, community and private sectors in plant genetic resources conservation.

In almost all coconut growing communities, there is presently little information available on the status of the genetic diversity maintained by coconut growing communities. In the past, the measurement of genetic diversity in coconut depended largely on morphometric traits. The use of morphometric, farmers' knowledge and molecular markers to characterize farmers' varieties will assist in better understanding of the structure of genetic diversity both at a specific site and across regions.

In situ conservation has the distinct advantage of conserving already adapted germplasm that has naturally evolved in particular environments. However, there is no sustainable mechanism to effectively monitor and document the effect of *in situ* conservation without a specific conservation project and allocated budget in national programmes. A COGENT project is testing the viability of four coconut-based income generating technologies in 24 communities in eight Asia Pacific countries (Bangladesh, India, Sri Lanka, Indonesia, the Philippines, Vietnam, Fiji and Papua New Guinea): 1) production and marketing of high-value products from all parts of the coconut- the kernel, husk, shell, water, wood, leaves and roots; 2) intercropping cash and food security crops, 3) livestock/fodder production; and 4) production and planting of high-quality coconut seedlings which are raised in community-managed nurseries. The community-managed nurseries propagate seednuts for on-farm conservation from identified local varieties, which are selected by farmers in farmer participatory rapid appraisal of community genetic resources and coconut diversity fairs; and from introduced high-value varieties from other locations. Selected local varieties are paint-marked to identify suitable varieties both for *in situ* conservation and for propagation. The community-managed nurseries are informal seed systems not dependent on government resources, and because of this, they are envisioned to be a sustainable tools for promoting *in situ* and on-farm conservation. The project has identified and characterized 89 important farmers' varieties and total of over 62,000 seedlings from these farmers' varieties were conserved *in situ* and on-farm. An IFAD-funded follow up project to be implemented in 2005 to 2007 will increase the participants to 54 communities in 15 countries. Proposals are also being prepared to undertake a similar project in four African and four LAC countries for the support of the Common Fund for Commodities. Discussions are also underway to seek the support of the Global Environment Facility for a project on coconut *in situ* conservation.

On-farm conservation will not only conserve the original materials that have been sampled for *ex situ* conservation (through FGB, pollen or *in vitro* methods) but also those that have not been collected so far. Together with *ex situ*, on-farm conservation helps to conserve and use much larger genetic diversity of coconut.

Promoting conservation through use

The value of conserved germplasm is not maximized until it is used to benefit poor people. Accordingly, the coconut conservation strategy seeks to promote conservation though use. Mechanisms include the following initiatives: a) developing a globally-coordinated coconut breeding programme; b) community-managed coconut seedling nurseries; c) linking conservation with broader areas of research and development; d) development of catalogues of conserved germplasm and farmers' varieties; e) upgrading of the CGRD; and f) developing a catalogues and other public awareness materials on coconut high-value products and uses for food, nutrition and health.

Globally-coordinated coconut breeding programme

A proposed globally coordinated breeding programme would facilitate the use of available germplasm worldwide and expedite work on developing improved varieties.

Specifically, the programme aims to:

1. Further characterize conserved germplasm and farmers' varieties using morphometric and molecular marker techniques;
2. Screen and identify ecotypes tolerant or resistant to lethal yellowing disease and drought;
3. Improve yields for specific uses and adaptation;
4. Develop varieties which are suitable for the production of high-value products from husk, fibre, shell, meat, water, wood and leaves;
5. Develop technical support systems for national breeding programmes (i.e. information, pollen and embryo provision, etc.); and
6. Provide a platform to promote the dissemination and use of the results of the above-mentioned coconut breeding projects to achieve socioeconomic and environmental impact.

Ultimately, the programme should be able to significantly increase the choice of varieties and hybrid cultivars among coconut growing countries, by maximizing the use of available genetic resources for breeding purposes, and improve the quality of the planting materials for distribution to users or farmers.

Community-managed coconut seedling nurseries

In the past, many coconut farmers relied on planting materials produced by government agencies, which were generally inadequate and incapable of serving large numbers of farmers. Because they earned marginal incomes from coconut, there was not much strong conscious effort to select planting materials from their best varieties and palms. Consequently, the planting of important local and introduced varieties was limited and the full potential of this diversity was not maximized. Through its "Poverty reduction in coconut growing communities" project (described in the section on *in situ* and on farm conservation), COGENT has developed a mechanism to address this constraint through the establishment of a non-Government dependent community-managed coconut seedling nursery in three pilot communities per country in initial eight Asia Pacific countries. This project which was initially implemented in eight Asia Pacific countries has convinced Indonesia, the Philippines and Vietnam to expand the number of communities using national budgets. In addition, to the IFAD-funded follow up project in 15 countries, proposals are being prepared to expand this project in 24 countries worldwide.

Under the project, farmers' preferred varieties will be conserved *in situ* and on-farm and, based on morphometric and molecular marker characterization, some will be selected for *ex situ* conservation either in national genebanks or in the ICG. This will enhance the value of these *ex situ* collections as they will address framers' varietal preferences. Conversely, some high-value varieties already conserved in the national genebanks and ICGs which will be identified for introducing in the participating poverty reduction project communities would provide further links between conservation and use.

Linking conservation with broader areas of research and development

In 2002, the coconut community launched a global Coconut Research for Development Programme (PROCORD), which provides a platform for the use of the genetic resources conserved by member countries. Under PROCORD, COGENT has been assigned to coordinate research on genetic resources improvement and socioeconomics and policy support; CIRAD on agronomy and farming systems and crop protection; and APCC on processing and marketing. COGENT is collaborating with CIRAD to identify germplasm that could be used for testing different coconut-based farming systems and for evaluating drought tolerance as well as germplasm for the lethal yellowing disease studies and with APCC to identify farmers' varietal preferences and processors' preferences both for processing and consumption. These research activities are at their initial stages but could provide strategic advantages in linking conservation of diversity and use.

Developing catalogues and other public awareness materials on coconut varieties, coconut high-value products and uses for food, nutrition and health

To fully appreciate the value of both *ex situ* and *in situ* conserved germplasm, there is a need to document their origin, vegetative and fruit characters and their adaptation to biotic and abiotic stresses. As many researchers, students and farmers do not have the opportunity to travel and see these varieties in the countries where they are located, the publication and dissemination of catalogue containing such information will popularize these genetic resources and promote their further study and possible use.

Upgrading the International Coconut Genetic Resources Database (CGRD)

The CGRD contains passport and morphometric characterization data of 1416 conserved accessions in 22 countries worldwide. Molecular marker data (using microsatellite kits) from these collections are also registered in the CGRD. The CGRD is used by coconut breeders worldwide to identify accessions they would like to use in their breeding. The CGRD is also distributed to major libraries in coconut growing countries. Together with the catalogues of conserved germplasm and farmers' varieties, which will also be distributed similarly, researchers, teachers and students could use them to further study and understand the nature and value of coconut genetic resources. These initiatives, no doubt, will promote greater use and consequent conservation of these genetic resources.

To enhance the value of the CGRD, there is a need to upgrade the data. At present, it contains passport and some characterization data for 1416 accessions in 28 conservation sites in 22 countries. However, out of the 1416 accessions, only 1155 have 25-75% of the needed characterization data; only 503 have molecular data and only 628 have pictures. Upgrading the database would involve collecting more morpho-agronomic characterization and molecular marker characterization data and pictures for the initial 22 countries and additional coconut growing countries in the near future.

Priority activities under the Global Coconut Conservation Strategy

The global coconut growing community advocates a progressive conservation and use strategy with the ultimate goal of providing sustainable benefits to poverty-mired coconut farmers and coconut growing countries worldwide in the short, medium and long term. The previous sections of this strategy paper summarized the scope and status of coconut conservation to date and the gaps that need to be addressed. This section recommends priority activities that need to be implemented in the next 10 years, if resources become available.

The role of COGENT in developing and implementing the strategy is important for two major reasons: 1) the network is owned and managed by 38 coconut producing countries, with membership currently increasing – national genebanks are owned by national programmes; the international genebanks are hosted and maintained by strong national programmes; and 2) the COGENT Steering Committee, which represents major coconut producing countries, decides on research priorities and provides oversight to the implementation of agreed programmes

Additional collecting and conservation of germplasm in national genebanks

1. Collecting in the South Pacific island countries for germplasm under threat from global warming, drought and typhoons for conservation in national and international genebanks.
2. Conservation of 8-10 accessions which have known resistance/tolerance to the dreaded lethal yellowing disease in ICG-AIO and ICG-LAC and screening of additional germplasm through molecular market techniques.
3. Conservation of Vanuatu coconut germplasm to protect them against the foliar decay disease in Vanuatu; and of Philippine coconut germplasm to protect them against the cadang-cadang disease.
4. Identification, collecting and conserving drought-tolerant germplasm.
5. Collecting and conserving materials with specific characteristics for coconut product value addition that could produce high-value products for poor coconut farmers.

Accelerate the full establishment and upgrading of the ICGs to make them more effective and better able to promote the use of coconut diversity in coconut producing countries.

1. Regeneration of old palms of 50 accessions in the International Coconut Genebank for Africa and the Indian Ocean. The old palms (more than 40 years old) at the Marc Delorme Station will be regenerated from 2005 to 2007 using controlled pollination. The Trust has provided a research grant for this purpose.
2. Establishing the ICG-LAC in Brazil to conserve important germplasm for the LAC region
3. Developing an expansion area for the ICG-SEEA in Manado, Indonesia
4. Increasing the number of conserved material up to a maximum of 200 accessions in each ICG host country - germplasm importation from ICG regional member countries, growing embryos *in vitro,* transplanting resulting seedlings and maintenance in the FGBs.
5. Development of the ICGs as 'Centers of Excellence" through upgrading and capacity building:
   - Expansion of current embryo culture laboratories in Indonesia, and Papua New Guinea to accommodate the importation and propagation and field conservation of 148 and 145 accessions,

respectively

- Research and training to increase recovery rates from embryo culture by improving acclimatization techniques at the *in vitro* and *in vivo* stages
- Research and training to further refine the cryopreservation techniques using a range of varieties for long tem conservation of coconut
- Research and training to increase the efficiency of rapid regeneration of conserved materials through somatic embryogenesis
- Research and training to evaluate the genetic fidelity of cryopreserved materials through molecular marker techniques
- Research and training to conduct molecular marker based characterization and genetic diversity analysis of conserved germplasm in national and international coconut genebanks to eliminate unnecessary duplicates and in farmers' fields and to identify accessions to be conserved the national and international coconut genebanks.

In situ and on-farm conservation of important farmers' varieties

The ADB-funded project in 2002-2004 conserved 89 farmers' varieties *in situ* and on farm in 24 communities in 8 countries. An IFAD-funded follow up project to be implemented in 2005 to 2007 will increase the participants to 54 communities in 15 countries. Proposals are also being prepared to undertake a similar project in four African and four LAC countries for the support of the Common Fund for Commodities. Discussions are also underway to seek the support of the Global Environment Facility for a project on coconut *in situ* conservation. It is envisioned that during the 10-year duration of the strategy, a total of 30 countries would have effectively conserved representative farmers' varieties *in situ* and on farm.

Upgrading the International Coconut Genetic Resources Database

To enhance the value of the CGRD, there is a need to upgrade the data. At present, it contains passport and some characterization data for 1416 accessions in 28 conservation sites in 22 countries. However, out of the 1416 accessions, only 1155 have 25-75% of the needed characterization data; only 503 have molecular data and only 628 have pictures. Upgrading would involve collecting more morpho-agronomic characterization and molecular marker characterization data and pictures for the initial 22 countries and additional participating countries.

Development of national coconut germplasm conservation strategy

Using the Global Coconut Conservation Strategy as a framework, each coconut producing country will develop a national conservation strategy. These strategies will flesh out the priority projects identified in the global conservation strategy and identify additional priority projects that are important to each country and to the region.

Development of Regional Coconut Conservation Strategies

Using the national and global conservation strategies, regional conservation strategies will be developed for South Asia, Southeast and East Asia, South Pacific, Africa and the Indian Ocean, and Latin America and the Caribbean.

Chapter 4

Characterizing diversity

Morphometric methods of determining diversity in coconut

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Introduction

Coconut is cultivated all around the intertropical belt, mainly in coastal areas. Its large genetic diversity has long been recognised. Attempts to account for this diversity have resulted in various classification systems like those proposed by Miquel in 1855, Narayana and John in 1949 or by Lyanage in 1958 (see the discussion of these systems in Child 1974). Despite the efforts of these authors, it was not always easy to obtain a completely consistent system, because some of the traits used in these classifications represented variation between populations, while others were polymorph within a given population. Describing the morphological and agricultural aspects of coconut genetic variation appears to be a complex task and requires the observation of a fairly large number of quantitative traits. It is necessary to take into account intra-, as well as, inter-population variation. It remains that some features of genetic variation have a great practical and theoretical significance.

A consideration of growth habit - precocity and flowering biology (Rognon 1976) - leads us to the usual distinction between the predominantly cross-pollinating Tall and the usually self-pollinated Dwarfs. Such a distinction is obviously of great significance in field management and for seed production. For the sake of completeness, two other categories should be added. The semi-Talls, which are self-pollinating like Dwarfs, but grow faster and have a bole, like the Talls; the Compact coconut which is represented by a single cultivar - the Niu Leka. In spite of its short stature, it has all the characteristics of a Tall and is cross-pollinated.

Whitehead (1966) proposed protocols for the study of fruit composition. Harries (1978; 1991) refined them and proposed a theory of coconut evolution. According to him, coconuts growing in the wild need to present some adaptive traits including the capacity to float on sea to allow natural dissemination and to grow in coastal areas. These adaptive traits result (among other traits) in elongated and triangular nuts, having a high percentage of husk. Slow germination increases the possibility of reaching long distances by floatation. In contrast, domestication of coconut mainly for drinkable water - according to this theory – favoured genotypes with round nuts and high water content at the cost of husk thickness. Fast germination and a strong rooting system would also be advantageous. In latter stages, fruits of either type (i.e. the 'wild' type also called *Niu Vai* and the 'domesticated' type, called *Niu Kafa*) would have been transported by humans during their travels, as part of their supply of food and drink or with the purpose of planting them at the arrival site. Finally, the copra industry would have made use of either type of coconuts without distinguishing their differences to establish large plantations. The present diversity of morphological traits in coconut is considered as the result of these events and of subsequent gene exchanges between these two ecotypes. Harries (1981) proposed methods for identifying coconut varieties.

Using molecular markers, it is now possible to assess the genetic relationships between the coconut cultivars collected across the entire geographic range of the plant (see following articles on biochemical and molecular methods) and reveal other aspects of coconut genetic diversity. In fact, morphological and molecular traits are affected differently by evolutionary forces and thus, reveal different aspects of genetic diversity. At least some of the morphological traits are likely to be subject to strong (natural or artificial) selection pressure. In contrast, molecular markers are considered as selectively neutral. This is especially true of microsatellites, which are located in non-coding sequences. On the other hand, mutation, migration and genetic drift affect both types of markers in a more or less similar manner.

Another important difference between molecular and morphometric diversity is that the latter is strongly affected by environment and hence, shows significant level of genotype x environment interaction. This may be a serious hindrance to study genetic relationships of coconuts, particularly if we intend to compare results obtained from different places. The lack of such GxE interaction explains largely the success of molecular methods. On the other hand, it must be recognized that they would be useless without a good knowledge of the measurable – and often agriculturally meaningful – variation of phenotypic traits. Actually, considering such traits is essential from the beginning (sample constitution) to the end (interpretation) of a molecular study.

From the above, it is clear that studying morphometric variation of coconut can generate two kinds of results. The first is an evaluation of the agricultural potential of the cultivars tested; the second is a better understanding of the genetic diversity, in relation to results obtained with molecular markers. Both of these outcomes are important for plant breeding. While the first directly provides the value of selection criteria, the second serves as a guide to choose the cultivars to be introduced in a breeding programme, to maximize selectable diversity and/or heterosis.

Morphological characterization/evaluation of coconut can take place in a research station or on farm. The advantages of a research site are obvious. The populations under study are planted in controlled condition, preferably using appropriate experimental design involving replicated blocks and a control treatment. A workforce that is permanently on the spot allows observations over a long period. Even though such conditions seem to be ideal for accurately comparing coconut varieties, they represent a complex organization and results are available only many years after planting. They are obviously not adapted for assessing germplasm diversity in the framework of genetic surveys. In this case, on-farm studies are unavoidable and must rely on a reduced set of observations.

A list of the traits that may be included in such a study and a brief review of the statistical techniques commonly used to measure and interpret the results are presented. A review of the results of some morphometric studies realized in many parts of the world and the comparison of the resulting observations with the information obtained with molecular markers are also discussed.

Observations

Studying morphological diversity in coconut involves comparing traits that are measured on different parts of the plant. It is often useful to compare the results of different studies and this comparison is easier if standardized techniques are used. For details about which traits to measure and how to measure them, the reader can consult the standardized research techniques in coconut breeding (STANTECH) manual (Santos *et al*. 1996). In this paper, only the summary of the principles of such measurements is presented.

As stated above, morphometric observations can be performed in two very different contexts: *in situ* (generally in a farmer's field) and *ex situ* (i.e. in a research station). Obviously, there are observations that can be done in the second case and not in the first case. An overview of the possible observations is given in Table 1.

Some comments may be made on this list:

- General information: refers to data that are not directly used in the statistical analysis, but may be needed for its interpretation and for the subsequent use of germplasm. These data should be as comprehensive as possible.
- Speed of germination: may be added to *in situ* observation if nuts were sampled for transfer into a genebank.

Table 1. Summary of morphometric observations

	In situ **(STANTECH Chapter 2)**	***Ex situ*** **(STANTECH Chapter 7)**
General information	Sampling site location, purpose of cultivation, available information on origin, etc.	Passport data
Speed of germination	n.a. (see below)	Number of days to 25%, 50%, 75% and maximum germination, final germination rate
Vegetative data before flowering	n.a	From nursery to flowering: leaf emission, length and girth
Stem morphology	Diameter at 20 cm and 150 cm above soil; Spacing between leaf scars	Same Annual height increment (from measurement made at 6 and 10 years)
Leaf morphology	Rachis, petiole and leaflet measurements	(At approx. 8 years)
Leaf production	n.a.	(At approx. 8 years)
Inflorescence morphology	Stalk, central axis and spikelet measurements, length of branches	Same (at approx. 8 years)
Flowering	n.a.	Date of emergence of first flower, Flowering phases (2 years after first flower)
Fruit component analysis (FCA)	Weight of components and endosperm thickness	Same (measured 2-3 years after production starts)
Fruit appearance	Record shape of fruit, measurement of whole fruit, and nut length and diameter	Same, (measured 3 years after production starts)
Fruit set	Gives an approximation of 7 to 8 months harvest	n.a.
Copra per nut	n.a.	Same period as FCA
Fruit and bunch return	n.a.	Two periods: • Juvenile (measured 1-2 years after production starts) • Mature (measured 3-6 or 3-8 years after production starts)

- Vegetative data before flowering: values recorded after planting and just before initiation of flowering may be considered.
- Stem morphology: Do not use stem height unless ages are the same – prefer height increment.
- Leaf morphology: May be used for *in situ* studies if palms are approximately of the same age. If not, ratios between different parts of the leaf should be preferred.
- Fruit component analysis (FCA) - Two contrasting advice are given about the exact stages of maturation for performing analysis. According to Harries (1978), it should be done when the fruit is begin-

ning to ripen (when colour of the fruit changes from immature colour to brown). At this stage, part of the epidermis is turning brownish, due to drying. Other researchers prefer storing fruits in a shaded area (and – in rainy season – under a shelter) for a period varying from 15 days to 1 month (Meunier *et al*. 1977). This method is preferable if the main purpose of the FCA is to estimate the copra contents while the former is the only choice for *in situ* analyses. It is also probably better suited when one wishes to evaluate the liquid endosperm contents. In any case, the method adopted should be mentioned in the protocol.

Some of the measurements are made repeatedly, like fruit and bunch returns but it is not necessary to include all observations in the statistical analysis. Instead, the average of the observations from a set of samples (for fruit and bunch return) or the evolution during the period of observation (for vegetative measurements before flowering) may be considered. Introducing too many variables that are strongly correlated in multivariate analysis is not likely to improve the precision of calculations.

Determining a sample size always involves a compromise between the expected quality of characterization and feasibility. The larger the sample, the better are the results. Experience has shown that about 30 palms are a good compromise between accuracy and cost of measurement. For multivariate analyses, it is important to record all observations on an individual palm basis. A single missing observation will generally result in omitting all observations on the corresponding sample palm.

Statistical methods

There are some commonly used methods for presenting results of morphometric studies. Discussion of these methods does not go into mathematical details because these analyses are generally done using specialized software. More details on statistical methods adapted to genetic diversity analyses may be found in Perrier *et al*. (1999).

Simple statistics and graphs

The most obvious way of representing the observed results is in the form of tables. For quantitative traits (like petiole length), average and standard deviation for each treatment are tabulated. Coefficient of variation may replace standard deviation. Univariate ANOVA makes it possible to test for the existence of significant variation between cultivars. For qualitative traits (fruit colour, etc.), the percentage of individuals having a given value are given in the tables.

The use of a graphical representation (mainly scatter and bar diagrams) may be sufficient to visualize some striking features, as long as a small number of traits are involved. For example, Harries (1981) proposed to represent FCA results using two types of graphs. One is a scatter-plot graph with the percentage of husk as abscissa and the weight of whole fruit as ordinate. The other one is an equilateral triangular graph where the three components of the nut are represented as percentages. The scale for shell/nut ratio (from 15% to 40%) is on the base, the scale for water/nut ratio is placed upside down on the left side (from 40% to 15%) and the scale for endosperm/nut ratio (from 45% to 70%) is placed on the right side. Such a graph is very convenient, since the three components are given equal importance. The position of the representative points of a cultivar on these graphs corresponds to its type (wild, domesticated or introgressed).

Principal component analyses and related methods

The previous example represents probably the maximum of what can be done in analyzing multidimensional data by hand. However, morphometric data analysis involves generally 20 or more traits at the same time, which is almost impossible to visualize. One of the solutions to capture the most important factors of variation is to use principal component analysis (PCA) or a similar method.

PCA is adapted to quantitative data. Its principle lies in using linear transformations of the original data. The whole set of observations made on each individual may be interpreted as a point in a multidimensional space, with coordinates equal to the values of each trait. These coordinates are converted into a new set of coordinates, named 'principal components' using transformations that can be interpreted geometrically as translations, rotations and homothecies (dilatation of one or several coordinates). These components are linear combinations of the observed data and are ranked in decreasing order according to the percentage of the total inertia (the multivariate equivalent of variance) they account for. Principal components are easier to interpret because, unlike observed data (for example height increment and spacing between leaf scars), they are 'orthogonal', which means that they are not correlated. Moreover, most of the useful information is concentrated on the few first components. By plotting the first two principal components, it is possible to obtain the 'best' two-dimensional representation of the data. This representation is the best, in the sense that it includes the largest possible proportion of total variance.

To a certain extent, the PCA representation 'distorts' less the observed data, while representing them in the most convenient way. This poses a problem, when data may be represented with different units. The smallest the measurement unit, (thus, the largest the corresponding value), the largest is the influence of a trait on the result of the PCA. It is customary to standardize observation by dividing deviations from the mean value by the standard deviation of the corresponding trait, prior to performing the PCA itself.

Interpreting the results of a PCA involves the examination of the resulting plot - treatments that are represented by distant points differ from each other. The reverse, however, is not necessarily true, as a PCA plot is a projection of a high dimensional geometric object (i.e. the representative points of all individuals or treatments) on only two dimensions, treatments that have about the same values for the first two components may differ for other components. Thus, it is often useful to examine representations involving the third or the fourth component, which may reveal important variation factors. Finally, by inspecting the correlations between observed variables and each principal component, it is possible to know which trait(s) contribute(s) the most to variation.

PCA and related analyses involve matrix calculations and may be performed on computers using various software packages. For example, the PRINCOMP procedure of SAS® software performs principal component analysis; the CANDISC procedure performs canonical discriminant analysis (DA) and also computes Mahalanobis distances. A (canonical) DA is very similar to a PCA except that principal components are chosen based on the within treatment variance-covariance matrix, rather than on the overall variance-covariance matrix. The result is that in the scatter plots, distances between treatments (rather than distances between individuals) are maximized.

Mahalanobis distance

Methods related to PCA are very useful to visualize the most prominent differences between accessions and to relate them with observed traits that explain the major part of these differences. This is possible only by discarding part of the useful information. If the main aim is to assess how different accessions are, regardless of which traits contribute most to this difference, the full information may be exploited by calculating genetic distances. One of the most popular distance index used in studying morphometric traits is the Mahalanobis distance. It is related to the classical Euclidean distance. The Euclidean distance between treatments *i* and *j* is

$$D_{ij} = \sqrt{\sum_k (x_{ik} - x_{jk})^2}$$

where x_{ik} and x_{jk} are the respective values of trait number *k* in treatments *i* and *j*. The Mahalanobis distance is actually a Euclidean distance, performed after data transformation involving the within-treatment variance-covariance matrix, just like in DA. The significance of Mahalanobis distances can be determined with a Hotteling T^2 test.

Clustering methods and dendrograms

As distances are symmetric, they may be represented with a triangular two-way table. However, when the number of accessions is large, such a table is not always easy to read. Moreover, the aim is to group this large number of treatments into a smaller number of clusters. There is an array of methods to perform this operation and it would be difficult to list them all. Incidentally, the eleven methods proposed by the CLUSTER procedure of SAS software are only a small sample!

At the beginning of ascending – or agglomerating – methods, each treatment is considered as a cluster. Then, each step consists in merging the two closest clusters in order to form a new cluster, which replaces the two old ones. The unweighted pair group method, using average or UPGMA, is often used in genetic diversity studies (AVERAGE option in the CLUSTER procedure of SAS). With this method, the distance between two clusters is the average distance between pairs of treatments, one in each cluster. This method tends to join clusters with small variances and tends toward producing clusters with the same variance. There are also descending methods: all treatments are placed in a large cluster. At each step, a cluster is split into two smaller clusters to maximize distance.

Qualitative observations

Most observations considered so far are quantitative. However, some of them are qualitative (colour, shape of fruit, etc). Is it possible to introduce them into multivariate analyses? One solution is to create a quantitative variable for each possible value (or modality) of the trait. For example, if in a survey, palms with green, brown and red fruits were observed, three variables will be attributed to these colours. Palms with fruits of a given colour will be attributed value 1 for the corresponding colour and 0 for the two others. In this manner, the average value of each colour variable in a population will be the proportion of palms having the corresponding colour. Such a solution is applicable for producing PCA plots involving both quantitative and qualitative variables. It must be noted, however, that the statistical tests based on Mahalanobis distances assume normality, which is clearly not true in this case.

At any rate, it is interesting to mention that in rare instances, the colour of inflorescence, nut size and shape and other qualitative traits may serve as distinct genetic markers like the pink/purple female flowers and round small nuts of the Pilipog Green Dwarf, the rough and scarified exocarp of the Agta Tall and the thick (5-7 mm) shell of the Tutupaen Tall from the Philippines.

Diversity indexes

Populations (varieties, cultivars) do not differ only by their mean values but also by their diversities. In the case of a single quantitative variable, standard deviation (or coefficient of variation) is an obvious indicator. In the case of qualitative variable, one of those two diversity indexes may be used:

Simpson index: $$D = \frac{1}{\sum_i p_i^2}$$

Shannon-Weaver index: $$H = -\sum_i p_i . \ln p_i$$

where p_i is the observed frequency of the i^{th} modality of the trait. The Shannon-Weaver index varies between zero (population is uniform for the trait) and the logarithm of n, the number of possible values of the trait (diversity is maximal and all possible values are equally represented). Simpson Index varies between 1 and n in the same conditions.

Application

Fruit characters, leaves and germination in Mexico

The studies conducted by Zizumbo Villarreal and Pinero (1998) and Zizumbo Villarreal and Colunga-Garcia Marin (2001) are representative of the differences between morphometric studies made *in situ* and in research stations. The first one involves 41 populations of both West and East coasts of Mexico. Observed traits were 11 FCA traits, to which six ratios involving the previous traits were added. The second was made on 18 populations, with 11 traits measured on the leaf, to which eight calculated values were added. All populations of the second study were represented in the first one.

Even though the traits involved in these studies are different, they are able to identify similar patterns of variation. For example, Atlantic Tall coconut differs from the Pacific Tall through more elongated fruit, a higher percentage of husk and a lower percentage of liquid endosperm. Similar observations are also made in Costa Rica (Vargas 1995). However, Atlantic Talls also produce one or two leaves less in a year, and they tend to have shorter leaves, but longer petioles. Their germination is also much slower (Zizumbo Villarreal and Arellano-Morin 1998). These applications find also differences within the Pacific Tall; in general, cultivars with larger nuts and higher liquid endosperm (named Pacific Tall 1) also have a more uniform germination compared to the others. They also tend to have similar leaf characters, although this tendency is less obvious.

Diversity in the South Pacific for fruit characters

Ashburner *et al*. (1997) studied 29 cultivars from South Pacific. Some of them are representative of the majority of local coconuts, while others correspond to 'named types', i.e. relatively rare variants that are cultivated for special purposes. Measurements were done according to the technique of Harries (1981). Sample size varied from 5 to 45. Data were subjected to DA and to hierarchical classification analyses. This led to the identification of six groups: wild, domesticated, and three groups with intermediate fruit characteristics: the Melanesian, West Polynesian and East Polynesian groups. The Phoenix Tall formed the sixth group. Existence of a clonal variation was studied by linear regression using the geographical longitude of the sampled population and two variables; the fruit weight and husk proportion. Both of those variables increase from West to East (but such a trend appears only after excluding cultivars identified as 'domestic' and 'wild').

This study tends to confirm the idea of domestication in Southeast Asia. The 'domesticated' phenotype tends to predominate to the West and to be less marked when progressing eastward. However, this picture is somewhat distorted by the movement of germplasm which has continued after the colonization of the South Pacific.

Thus, the farther the population from the main domestication centre, the stronger is the tendency toward 'wild' nut characters. However, microsatellite alleles that become more frequent in the Eastern Pacific are not those of the Indo-Atlantic group. This suggests that the wild coconut encountered by the Austronesians during their conquest of the Pacific had only one common point with the Indian coconuts, i.e. they had not been selected for high liquid endosperm content. Otherwise, they had grown in very distant place for a very long time and, as a consequence, their genetic structure diverged during that period.

Multivariate analysis on coconut populations in the Philippines

In 1981 (PCA ARD Annual Report), using the coarse grid sampling strategy proposed by the IBPGR (now IPGRI) and applying the Mahalanobis generalized distances method as suggested by Meunier (1976) and cluster analysis, Santos *et al*. (1984) identified 29 accessions of coconut populations from 100 geographically isolated sites in the Philippines. The traits studied included measurements on the inflorescences from 10 palms, and stem and fronds from 30 sample palms per site from 4-5 sites within a grid. It was interesting, although not surprising, to find populations from sites 1000 km apart, to be in one cluster. This could be explained by the fact that as people migrate, they bring coconut along with their treasured possessions and this is still a common practice. The current studies being made using molecular markers could further shed light on this phenomenon. Practically, the clustering of populations with similar genetic distances for the traits studied made it possible to delimit the number of collections to be made while ensuring the capturing of the widest array of diversity *ex situ* at the least cost and the identification of interesting populations (see section on qualitative observations). The study not only made it possible to estimate the diversity of coconut in the country but also, more importantly, involved farmers in the *in situ* conservation of coconut varieties.

Diversity at the global level

N'Cho *et al*. (1993) studied 17 Tall cultivars from the collection at Marc Delorme Research Station in Côte d'Ivoire. These cultivars covered a large part of the coconut's range of distribution. Twenty-three variables were taken into account: 3 measurements on the stem, 6 observations and 1 calculated variable on the leaf, 5 on the inflorescence, 7 on the fruit. Bunch and fruit yield were recorded during the 6-10 year period. Thirty palms were studied for each treatment. The first component of the DA was found to be highly associated with robustness of the stem and with length of the petiole, while the second was associated with fruit size (and negatively associated with yield).

Broadly, the main features of the resulting plot could be described in terms of the difference between 'wild' and 'domesticated' phenotypes. The cultivars that correspond best to the *Niu Vai* type are those from South East Asia, the Kar Kar Tall and the Rennell Island Tall, while cultivars from West Africa and India correspond to the description of the Niu Kafa type. Cultivars from East Africa and from the Andaman Islands and also from the South Pacific lie in between. To some extent, these cultivars have some of the characteristics of the extreme cases, but they also vary greatly in vigour and in fruit characteristics.

Using clustering methods, it is possible to group populations into eight groups, whose members have similar origins. However, any attempt to make larger groups results in grouping cultivars coming from very different regions (and with completely different genetic makeup). For example, the Rotuman and Tonga Tall are in a cluster including most

Indio-Atlantic cultivars. This suggests that, due to selection pressures, similarities at the phenotypic level do not imply close genetic relationship. Reciprocally, in the case of the Rennell Island Tall and of the Solomon Tall, which are geographically close enough to exchange genes (and indeed, have similar genetic features), the striking differences in their fruit and inflorescence traits indicate that such differential selection pressure have continued until the present time.

Environmental effects and GxE interaction in Dwarf cultivars

This section illustrates the effects of environment on fruit characters in Dwarf coconut. Three Dwarf cultivars are considered here - the Madang Brown Dwarf (MBD), the Malayan Red Dwarf (MRD) and the Malayan Yellow Dwarf (MYD). They were observed in Vanuatu and in Côte d'Ivoire. The number of sample palms analysed varied between 50 and 100 per treatment. The number of fruits analysed was about 1000 in Vanuatu and more than 3000 in Côte d'Ivoire.

Table 2 shows fruit weight and its components in both environments. In Vanuatu, MBD and MRD have similar characteristics and their fruits are bigger than that of the MYD. Similar observations are made in PNG (CCRI 1990). In Côte d'Ivoire, environmental conditions are less favourable and the fruits of the Malayan Dwarfs are smaller than in Vanuatu. The traits that are the most affected are the shell and the liquid endosperm. The reduction is much more pronounced in the MBD and its fruits are smaller than those of the MYD. Note the abnormally low quantity of liquid endosperm (Table 2).

Table 2. Fruit weight and its components in three Dwarf cultivars in two environments

Cultivar	Environment	Fruit	Husk	Shell	Solid endosperm	Liquid endosperm
MBD	Vanuatu (V)	1376	285	160	681	250
	Côte d'Ivoire (C)	739	240	72	392	35
	C/V%	*53.7%*	*84.3%*	*44.8%*	*57.5%*	*14.1%*
MRD	Vanuatu (V)	1356	295	152	656	253
	Côte d'Ivoire(C)	1176	301	128	591	157
	C/V%	*86.7%*	*102.3%*	*84.1%*	*90.0%*	*61.8%*
MYD	Vanuatu (V)	1036	233	111	500	193
	Côte d'Ivoire(C)	864	199	96	446	123
	C/V%	*83.3%*	*85.4%*	*86.2%*	*89.2%*	*63.8%*

The C/V% is the ratio of the values observed in Côte d'Ivoire over the values observed in Vanuatu.

The existence of variation due to environmental effects is not surprising in coconut. However, the behaviour of the MBD is a clear illustration of GxE interaction (probably due to the fact that the MBD is especially sensitive to attacks of *Pseudoobscura*). This interaction does not affect only the weight of the different components, but also the relative composition of the fruit. In Côte d'Ivoire, the MBD differs from the others through a high husk to fruit percentage. In Vanuatu, this trait has very similar values in the three cultivars.

Conclusion

Examples provided in this paper and in the preceding article on biochemical and molecular markers illustrate the many ways one can assess coconut genetic diversity. Molecular markers have two great advantages: their expression is independent from environmental effects and their number is virtually unlimited. Nevertheless, they cannot replace the morphometric approach for two reasons. This approach is fundamental to understand the agricultural value of coconut cultivars. Such an understanding is important from an economic point of view as well as for efficient conservation of genetic diversity. Coconut is essentially a cultivated plant and a large part of its diversity is due to continued selection by farmers for specific uses. The other reason is that they are not affected in the same manner by evolutionary forces, and thus, they give information that molecular markers could not provide alone.

Even so, there are many common aspects in the results of molecular and morphometric studies. The studies made in Mexico showed very similar results whichever type of trait is used, e.g. leaf traits, fruit components, using molecular markers or isozymes (Zizumbo Villarreal *et al*. 2002). This is due to the fact that populations on the Atlantic and Pacific coasts have very different origins. Even on the Pacific Coast, a certain differentiation exists because coconut introductions occurred from three different regions: Philippines, Panama and Solomon Islands (Zizumbo Villarreal 1996). However, classification varies somewhat between studies because these three origins are within the Pacific group and that there have probably been crosses between coconuts from different sources.

It is not surprising that different markers often lead to similar conclusions. Correlations between the variations of different traits are expected simply as an effect of random variation between populations that have evolved independently. Even if the genes corresponding to the concerned traits are neutral, these populations accumulate different alleles at each locus due to random sampling of their genes at each generation. Considering the genes that were subjected to differential selection in the environments where they grow, these correlations may be reinforced. Thus, the general rule is that a large portion of the information which can be obtained from genetic markers is independent of the nature of the markers (Lebrun *et al*. 1999b; Teulat *et al*. 2000).

Nevertheless, the most interesting situations correspond to exceptions to the above rule. As mentioned earlier, 'wild type' coconuts from India and from the South Pacific have a different genetic structure in spite of their phenotypic similarities. This shows that the 'wild type' are heterogeneous - their common ancestor is also the ancestor of the 'domesticated' type. This also confirms the ancestral status of the corresponding traits. On the other hand, the Kappaddam Tall, found on the Indian West Coast has a distinctively 'Niu Vai type' fruit (Harries 1978), but its genetic structure is very similar to those of the predominant local cultivar. Initially, it was an exotic cultivar from Southeast Asia (Lebrun *et al*. 1999a). Apparently, the local farmers appreciated its fruit characters and succeeded in maintaining them through selection. In the same time, most of the exotic genes – i.e. those which are not related to the selected traits – were eliminated due to cross-pollination with local coconuts.

Besides its obvious use for characterizing cultivars, the morphometric approach to determining genetic diversity provides valuable information on the role of informal selection on the evolution and the maintenance of genetic diversity in coconut. This information suggests that the conservation of genetic diversity will be more efficient if farmers' participation is considered as an important component of the conservation system.

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Biochemical and molecular methods for characterizing coconut diversity

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Introduction

The various coconut palm collections worldwide are veritable genepools from which geneticists can tap to create or improve existing varieties. However, if a collection is to be used, it needs to be correctly labelled and cultivars in collections need to be precisely described, in terms of their morphological and genetic traits. As the latter are independent of the environment, they amount to a reliable cultivar identity card. Once precise labelling has been completed, the collection can be reduced by discarding duplicates and by limiting the number of representatives in the case of cultivars with low polymorphism. Such a reduction in numbers leads to considerable savings in conservation costs. Coconut palm collections cover large areas of land and thereby entail substantial management, conservation and renewal costs. Once cultivars have been correctly identified, it becomes possible to compare them on a worldwide scale. In this way, it can be seen that specific types such as the Malayan Yellow Dwarf designation may conceal different cultivars or off-types.

In a disease control context, Lethal Yellowing among others, it is paramount to identify with certainty those cultivars that display tolerance, or even resistance. It is just as important to ensure that any commercially produced hybrid corresponds to what it was claimed to be. This implies that the identity of the parents should be given special attention.

Different genetic markers

Different types of traits have been used to characterize genetic diversity in coconut populations: firstly, using traits which only require observation of the phenotype. Phenotypic observations have the great advantage of being directly related to agronomic traits. However, they are largely subjected to selection and to environmental conditions. A variety of morphologic traits was used by N'Cho *et al.* (1993) to describe the diversity of 17 Tall cultivars from the whole coconut cultivation area, and fruit traits were used by Ashburner *et al.* (1997) to describe the structuring of 29 cultivars from the South Pacific (28 Talls and 1 Dwarf) into genetic groups. In an initial study involving 17 morphological fruit traits, Zizumbo-Villarreal and Piñero (1998) separated Mexican coconut palms into three groups: two groups of Pacific Talls and one group of Atlantic Talls. In a more recent study, 19 traits were used by Zizumbo-Villareal and Colunga-García Marín (2001) to characterize 18 populations of coconut palms, with or without the presence of Lethal Yellowing. Unfortunately, these analyses did not make it possible to compare the same cultivar at different sites or over different time spans. Apart from fruit traits, most other morphological characteristics reveal mainly the dichotomy between Tall and Dwarf cultivars. It was therefore necessary to develop new tools for characterizing cultivars, independently of their growth habit and associated traits.

Biochemical markers

Biochemical markers, such as isozymes (Benoit and Ghesquière 1984; Cardeña *et al.* 1998) or polyphenols (Jay *et al.* 1988), were first used at the beginning of the 1980s to describe the diversity of coconut collections. Unlike with morphological traits, biochemical markers do not require measuring different characters from different organs in a full-sized palm. It is enough to take an organ sample (leaflet, root, etc.) to reveal the biochemical identity of the palm.

Isozymes

Isozymes, which are different forms of the same enzyme, are proteins produced by RNA translation. They are therefore genetic markers, but given their low polymorphism in coconut, isozymes proved to provide very little information for diversity studies. Nonetheless, isozymes were used by Fernando and Gajanayake (1997) on six cultivars from Sri Lanka. Of the six enzyme systems tested on leaf extracts, only two monomeric esterase loci and one dimeric peroxidase locus proved to be polymorphic, with 2, 3 and 2 alleles, respectively. These results tally with those found by Hartana *et al.* (1993), who tested six systems, three of which were polymorphic. No genetic determinism of the bands was suggested. The most important study was carried out with isozymes by Benoit and Ghesquière (1984), who screened 31 enzyme systems, 12 of which displayed little or no activity, 10 were non-polymorphic and 9 were legible and polymorphic. Although the genetic determinism of the nine systems was not entirely elucidated, only two alleles per locus were found. Cardeña *et al.* (1998) were no luckier, since they discovered two enzyme systems (peroxidase and endopeptidase) with two alleles each from testing four cultivars and two hybrids. Nonetheless, isozymes can be used for one-off studies, such as differentiating between the Rennell Island Tall (RIT) and the West African Tall (WAT) (Cardeña *et al.* 1998).

Polyphenols

Leaf polyphenols are substances involved in plant defence reactions to aggression. They form a family of molecules of controlled chemical formula and abundance. The different types of polyphenols can be identified by HPLC (High Performance Liquid Chromatography). These markers were used by Jay *et al*. (1988) to sketch out an initial picture of coconut genetic diversity. However, later studies revealed that the polyphenol profiles had low repeatability, probably due to a major environmental effect. It was therefore difficult or even impossible to compare collections with each other, or to compare the same collection over several years. At the beginning of the 1990s, new types of markers came into being, which were much nearer to the genetic basis than chromosomes were. These markers, which were directly linked to the genome, offered the advantage of being independent of the environment. They were molecular markers.

Molecular markers

Different types of molecular markers were used at the outset to describe the diversity of coconut collections, and more recently to identify cultivars or individuals. What these markers had in common was to be directly linked to the genome, hence, in theory, to be independent of the environment, the age of the plants or their phytosanitary condition. Each genetic marker corresponded to a DNA sequence located at a precise spot of the genome (or locus), whose polymorphism between individuals was shown using different tools, which generally included enzymatic digestion of DNA, specific or random multiplication of selected sequences [polymerase chain reaction (PCR) amplification]. This polymorphism corresponded to variants (or alleles) of the sequence being studied. It appeared in the form of bands on electrophoresis gel after developing with a radioactive or non-radioactive stain (e.g. silver nitrate or fluorochrome). Depending on the case, a single band was associated with a locus and polymorphism corresponded to the existence or absence of the band ('dominant' markers). In other cases, each allele was associated with a different band ('codominant' markers), making it possible to differentiate between a homozygous individual and a heterozygous individual at the locus in question, which was not the case with dominant markers. Different types of markers were differentiated by the type of sequences considered, their position in the genome (nuclear or cytoplasmic genome, encoding regions or not), the detection technique, their specificity and reliability, and the mutation rate, which determined the evolution rate and degree of polymorphism observed. Lastly, the cost of analyses was an important choice factor.

PCR is a technique for the amplification of a DNA segment between two known sequence regions. Using specific conditions and procedures

(Erlich 1989), selected sequences are multiplied many times so that variation in them can be detected and described. PCR amplification currently takes between two and three hours, depending on the thermocycler used and the hybridization temperature adopted.

Restriction Fragment Length Polymorphism (RFLP)

Characteristics. RFLP markers are codominant markers that are more or less specific depending on the probe used (cDNA, genomic DNA, etc). They are difficult and quite expensive to use. They require the extraction of a large quantity of good quality DNA and operations are lengthy. It takes around two weeks after DNA extraction to read the bands.

Starting in 1995, various diversity studies were undertaken at CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement) using cDNA nuclear probes or cytoplasmic probes (the latter being quite well conserved from one plant to the other (Lebrun *et al.* 1998; Lebrun *et al.* 1999). Cytoplasmic genomes are usually much less polymorphic than the nuclear genome. However, they can be a source of information for establishing phylogenies, or retracing the domestication routes of a plant from its region of origin (Lebrun *et al.* 1999).

Nine cytoplasmic probes (Mitochondrial: Apocytochrome b, sub-units alpha and 6 of ATPase, cytochrome oxidase (cox) sub-units 1, 2 and 3, Chloroplast: Cp IR, Cp sal6 and Cytochrome F) where hybridized with coconut DNAs digested by nine enzymes (*Hind*III, *Eco*RV, *Eco*RI, *Ss*tI, *Bam*HI, *Bgl*II, *Dra*I, *Hae*III, *Hpa*I). Probe Cox1 displayed clear polymorphism, which was, moreover, identical for the two digestion operations: *Ss*tI and *Bgl*II. Cox 2, which was difficult to interpret, could show polymorphism with *Hae*III digestion. All the other enzyme-probe pairs were monomorphic. Consequently, little mitochondrial polymorphism was found, and no chloroplast polymorphism. Perera (2002) has confirmed these results in a study on the chloroplast genome.

The nuclear genome proves to be much more polymorphic. For instance, during studies conducted in 1995 and 1997, two batches of different probes were used to explore coconut palm diversity. In the first study (Lebrun *et al.* 1998), nine rice cDNA probes led to the discovery of 40 polymorphic bands, whilst in the second study (Lebrun *et al.* 1998), 20 rice, oil palm, maize and coconut cDNA probes revealed 60 polymorphic bands.

Procedure. Plant DNA was digested by a restriction enzyme that cut the DNA at a particular site. A large number of fragments were obtained in this way. These fragments were then separated according to their size by migration in agar gel under the influence of an electric field. After migration, the DNA was transferred to nylon membrane, then exposed to a probe (small DNA primer specific to the locus studied), which was either radioactive-labelled or non-radioactive-labelled (antibody-antigen complex, e.g. Digoxygenine).

Irrespective of the number of probes used, or their origin, the results as regards diversity structuring were comparable. However, this technique is laborious to use. In addition, with the discovery of the PCR technique, new types of markers came into being.

Randomly Amplified Polymorphic DNA (RAPD)

Characteristics. These non-specific (the DNA revealed may belong to another species, such as a fungus) codominant markers, once amplified by PCR, are quite simple to use and only require a small amount of DNA. They are obtained very quickly. Random primers are marketed in kit form. After extraction, it takes two days to display the bands.

Their repeatability remains doubtful and it seems quite risky to use them for comparisons between laboratories, or over different time spans.

Their ease of use and low cost have made them very attractive, but they are difficult to read and their low reproducibility makes them more useful for genetic mapping rather than diversity studies. Nevertheless, they can be used for one-off studies, such as analyzing a few cultivars from the South Pacific (Ashburner *et al.* 1997).

Procedure. DNA was amplified by PCR using short random primers. The amplification products were separated by migration in agar gel then displayed using a DNA intercalator, Ethidium bromide.

Amplified Fragment Length Polymorphism (AFLP)

Characteristics. These are dominant PCR markers, which are quite easy to use but sometimes difficult to interpret. A large number of markers can be developed on the same gel, which often makes for difficult reading, hence their limited use in diversity studies. Moreover, on coconut, each combination tested has few polymorphic bands. These markers are primarily used to saturate genetic maps. It takes around one week after extraction to display the bands (Perera *et al.* 1998; Teulat *et al.* 2000; Lebrun *et al.* 2001).

Procedure. Stage 1: Plant DNA was digested by two enzymes, one rarely cutting (recognition site of 6 bases, e.g. *Eco*RI), the other cutting more frequently (recognition site of 4 bases, e.g. *Mse*I).

Stage 2: Double stranded adaptors were ligated to the ends of the DNA fragments to serve as templates for amplification. Thus, the sequence of adaptors, followed by the adjacent restriction site, served as the ligation site for the restricted fragment amplification primers.

Stage 3: In order to reduce the number of fragments amplified, the amplification primers were elongated in 3′ (restriction site side) by one or two bases. Only the restricted fragments possessing the selective base(s) just after the restriction site were amplified. These fragments were separated by migration in acrylamide gel under the influence of an electric field. Visualization was either radioactive or non-radioactive (fluorochrome on automatic sequencers, silver nitrate, etc.).

Inverse Sequence-Tagged Repeat (ISTR)

Characteristics. These are specific, dominant and extremely polymorphic markers. However, most of the polymorphism is primarily found within populations, making them of little use for diversity studies. For instance, it is the only way of observing polymorphism within the Malayan Yellow Dwarf from Tanzania and from the Philippines (Rohde *et al.* 1995). Their development is lengthy and costly. Detection of polymorphism is more random than with microsatellite markers. It takes three days after extraction to visualize the bands.

Procedure. Coconut genomic DNA was amplified by primers specific to regions separating repeated sequences. The PCR products were separated by migration on acrylamide gel, and then detected by radioactivity incorporated during amplification.

Microsatellites or Simple Sequence Repeats (SSR)

Characteristics. These are codominant PCR markers, for which it is easy to identify alleles and loci, thereby enabling their use in population genetics. Their development is expensive, but their routine use is affordable. They are very useful for mapping studies, as they can be used to compare different maps with each other. They are highly polymorphic, highly repeatable, and easily transposable from one laboratory to another or from one year to the next. They are ideal markers for diversity studies (Perera *et al.* 1999; Rivera *et al.* 1999; Perera *et al.* 2000; Perera *et al.* 2001; Meerow *et al.* 2003). They formed the basis for a coconut diversity study and cultivar identification kit developed at CIRAD (Baudouin and Lebrun 2002). It takes around three days after extraction to visualize the bands.

Procedure. Coconut genomic DNA was amplified by PCR using primers specific to regions containing a microsatellite sequence. This type of sequence was characterized by repetition, many times, of a motif formed by 2 or 3 pairs of bases (e.g. GAGAGAGA..., TCTCTC... or

GTCGTCGTCGTC…). As these primers were placed either side of the microsatellite, they enabled specific amplification. As the number of repeats varied from one individual to the next, differences in PCR product lengths were detected by migration in agar gel (and developed with EB) or on polyacrylamide gel (developed radioactively (P33) or nonradioactively (silver nitrate or fluorochrome on an automatic sequencer).

Single Nucleotide Polymorphism (SNP)

Characteristics. SNP are markers characterized by substitution of a nucleotide. They are codominant. Obtaining them requires a great deal of prior sequencing work (e.g. EST (Expressed Sequence Tags) type data obtained on different genotypes), and validation, but their subsequent use is quite easy (PCR, detection). As 'mass' sequencing is not yet available for coconut, SNP markers have yet to be developed.

Procedure. SNP markers are frequent and well distributed in the genome. Their frequency varies depending on the species and on the regions of the genome: from 1 every 3 kb in man, this figure can fall to 131 pb in the case of an EST of barley cytochrome P 450 (Bundock *et al.* 2003) or 54 pb in the case of an EST encoding 6-phosphogluconate dehydrogenase from sugarcane (Grivet *et al.* 2001). Through their variable positions in the genome (coding or non-coding zones), they offer very strong potential for markers which are useful for labelling the genome, or for studying gene regulation.

They are detected in several ways:

- By sequencing (Bundock *et al.* 2003) (microsequencing or primer elongation);
- By analyzing the polymorphism of single stranded DNA conformation;
- By denaturing gradient gel electrophoresis;
- By mass spectrometry; and
- By DNA microchip hybridization (Schmalzing *et al.* 2000).

In the case of sugarcane, Grivet *et al.* (2003) aligned the sequences of different sugarcane cultivars listed in EST databases containing 230 000 sequences. The strictness of such alignments and the quality of the sequences are of great importance for SNP detection. The next stage was finding a restriction enzyme whose recognition site includes the SNP. This SNP was then validated by merely defining the primers either side of the polymorphic site, digesting the amplification products with the enzyme cutting into the SNP, and proceeding with gel migration of the restrictions.

Choice of markers to be used

Consequently, different types of markers can be used depending on the questions involved and the resources available. A comparative study conducted on 31 individuals representative of worldwide diversity showed that AFLP, microsatellite (Teulat *et al.* 2000) and RFLP markers give the same picture of coconut genetic structure. Although they shed some light on the domestication routes taken by the coconut palm (Lebrun *et al.* 1998), RFLP remained a difficult and laborious technique, which could easily be replaced by using PCR type markers. At the present, microsatellite markers seem to offer many advantages. They are quite simple to use, and enough of them exist to choose from and use the most efficient primers.

The coconut microsatellite kit

In connection with a project funded by the International Coconut Genetic Resources Network (COGENT) of the International Plant Genetic Resources Institute (IPGRI), the European Union (EU), BUROTROP (Bureau for the Development of Research on Tropical Oil Crops) and CIRAD, a kit has been developed for coconut diversity studies and cultivar identification. The purpose of the kit is to evaluate genetic diversity using microsatellite markers based on standardized methods that can be used by any laboratory with a minimum of equipment.

Kit contents – The microsatellites

The coconut microsatellite kit consists of:

- Primer sequences available for use by partners in developing countries;
- A set of coconut reference population data, consisting of allelic frequencies for all the microsatellite loci of the kit. This set is representative of global coconut diversity and serves as a reference for further studies;
- A document listing the procedures to be adopted for analysis of diversity in coconut using the microsatellite kit, including both experimental and data analysis protocols; and
- Software called Geneclass2 for assigning individuals to cross-fertilizing populations.

Out of 83 microsatellite primer pairs screened for their ease of development, reproducibility, legibility and number of alleles, 14 were chosen, four of which could be multiplexed by two. The kit also includes a technical manual for laboratory operations, along with population assignment software.

The 14 primer pairs in the kit (Table 1) have been used to study diversity on 571 individuals, spread over 136 cultivars. That figure is continuing to increase, since new populations are being characterized each month using this kit. The results are entered in the Coconut Genetic Resources Database (CGRD) and are accessible to the members of the COGENT network.

Table 1. The 14 microsatellite kit primer sequences

Locus	Repeat array	Primer sequences (5'- 3')	Size range (bp)	T1* (bp)	T2** ((bp)	Embl Genebank Accession no.
CnCir A3	(TG)15	AATCTAAATCTACGAAAGCA AATAATGTGAAAAAGCAAAG	228-248	228 228	240 240	AJ458309
CnCir A9	(GT)9 (GA)8	AATGTTTGTGTCTTTGTGCGTGTGT TCCTTATTTTTCTTCCCCTTCCTCA	89-115	097 097	089 089	AJ458310
CnCir B6	(GT)4 (CT)2 (GT)10 (GA)11	GAGTGTGTGAGCCAGCAT ATTGTTCACAGTCCTTCCA	196-226	196 204	202 202	AJ458311
CnCir B12	(CA)20 (GA)15	GCTCTTCAGTCTTTCTCAA CTGTATGCCAATTTTTCTA	135-189	163 163	169 169	AJ458312
CnCir C3'	(CA)12 X21 (GC)6 (AC)10 (AG)12	AGAAAGCTGAGAGGGAGATT GTGGGGCATGAAAAGTAAC	174-232	178 206	176 176	AJ458313
CnCir C7	(GT)7 (GA)16	ATAGCATATGGTTTTCCT TGCTCCAGCGTTCATCTA	147-189	165 167	161 161	AJ458314
CnCir C12	(CA)15 (TA)6	ATACCACAGGCTAACAT AACCAGAGACATTTGAA	161-185	167 167	183 183	AJ458315
CnCir E2	(CT)17 (GT)9	TCGCTGATGAATGCTTGCT GGGGCTGAGGGATAAACC	115-177	163 163	135 135	AJ458316
CnCir E10	(CA)8 (GA)11	TTGGGTTCCATTTCTTCTCTCATC GCTCTTTAGGGTTCGCTTTCTTAG	226-246	244 244	238 238	AJ458317
CnCir E12	(CT)6 (CCT)2	TCACGCAAAAGATAAAACC ATGGAGATGGAAAGAAAGG	162-174	174 174	164 164	AJ458318
CnCir F2	(TG)11 (AG)12	GGTCTCCTCTCCCTCCTTATCTA CGACGACCCAAAACTGAACAC	191-215	193 193	205 205	AJ458319
CnCir G11	(GT)9 (GA)9 TA (GA)4	AATATCTCCAAAAATCATCGAAAG TCATCCCACACCCTCCTCT	186-212	204 208	194 194	AJ458320
CnCir H4'	(TC)8 X4 (CA)5 (CGCA)5	TTAGATCTCCTCCCAAAG ATCGAAAGAACAGTCACG	218-236	230 230	230 230	AJ458321
CnCir H7	(CT)16 (CA)13	GAGATGGCATAACACCTA TGCTGAAGCAAAAGAGTA	127-149	133 133	139 139	AJ458322

*T1 = standard 1 = WAT 4
**T2 = standard 2 = MYD

Eventually, as the 14 microsatellites of the kit are available from CIRAD or IPGRI, this base should be enhanced by results from all the countries possessing collections. It will then be possible to compare the genetic profiles of the populations in collections in different countries and conclude on the identity or difference between cultivars with the same name.

In 2002, COGENT supported the training at CIRAD of 18 coconut researchers from nine countries (one biotechnologist and one curator per country) on the use of the microsatellite kit and its associated software. Subsequently, each country was given a research grant by IPGRI /

COGENT with funding from DFID to use the skills learned to characterize their local conserved varieties with at least one of seven varieties with known tolerance/ resistance to lethal yellowing disease as control. This research is currently ongoing.

Geneclass2 software

The kit is currently accompanied by Geneclass2 software developed with Institut National de la Recherche Agronomique (INRA). The need for this software comes from the cross-fertilizing nature of Tall coconuts. Unlike clones or self-fertilizing varieties, a Tall cultivar comprises a set of genotypes, each of which is different. It can only be identified with molecular markers through the frequencies of the different alleles at the loci tested. In addition, the number of individuals observed is always limited, meaning that these frequencies are only known with a degree of uncertainty. Identifying the population of origin of one or more individuals therefore means resorting to probability calculations.

The method adopted is a Bayesian method (Baudouin and Lebrun 2001). It requires establishing a set of samples representative of the main known cultivars, which are then compared to 'candidate' samples to be identified. Geneclass2 software can then assign a probability to each proposal of the type 'the candidate comes from cultivar x'. This probability is a ratio of the 'score' of cultivar x to the sum of the scores of all the reference populations. The score is the probability of obtaining the candidate, given the reference sample. It is calculated taking into account the uncertainty of allelic frequencies.

This probability is calculated by considering the hypothesis that the candidate actually belongs to one of the reference cultivars, which is not necessarily true. Another test therefore has to be carried out and the Geneclass2 'exclusion' method makes it possible to calculate the probability that the candidate belongs to a reference cultivar. For this calculation, it is necessary to simulate a random sample of the genotypes of that population. The probability of belonging to the cultivar amounts to the percentage of simulated genotypes that obtain a lower score than the candidate.

Geneclass2 software performance

The efficiency of the Bayesian procedure was tested by attempting to determine the population of origin of the reference samples. The samples were representative of the main coconut cultivars. Some cultivars were represented by several populations that could differ slightly, and on the average, five individuals were sampled. Each individual was drawn from the reference database before seeking its origin. This precaution was taken in order to make the test more realistic: in actual population assignment, the tested individual and the reference samples form distinct sets. The individual assignment tests were approximately 50% successful (the population identified was indeed the population of origin). When the scores of the individuals in the same sample were cumulated, precision was substantially improved – the cultivar of origin was correctly identified in 72% of cases[1] (Table 2).

Table 2. Result of assignment test with Geneclass2

Group	Same population	Same cultivar	Same area (could be the same cultivar)	Other (within the same group)	Total
Pacific					
Dwarf	19	0	0	0	19
Panama	2	0	0	0	2
Southeast Asia	11	0	6	0	17
Micronesia, Polynesia	6	4	1	0	11
Melanesia	20	6	12	10	48
Indo-Atlantic	18	0	1	2	21
Total	**76**	**10**	**20**	**12**	**118**
%	**64**	**8**	**17**	**10**	

In 17% of cases, the cultivar identified had another name but came from a neighbouring region. It was highly likely that some biologically identical cultivars were given different names, either because they were described by different people, or because the corresponding populations had different morphometric characteristics due to environmental or age differences. It was therefore reasonable to assume that a proportion of the 17% actually corresponded to correctly classified cultivars.

In 10% of cases, the samples were attributed to cultivars in the same group, but from another region. In a small number of cases, assignment was ambiguous. This may have involved cultivars for which genetic differences were too slight to be picked up with the number of individuals used. The possibility of germplasm exchange over long distances could not be ruled out either.

The method gave different results depending on the groups of populations. For instance, each Dwarf cultivar was correctly identified. These cultivars are self-fertilizing and extremely homogeneous, making it easier to distinguish between them. On the other hand, most of the cultivars that were imprecisely identified came from Melanesia. In fact, more populations were sampled from this region than from any other. As a result, some populations were very similar to each other and thus difficult to distinguish with only five individuals per population.

[1] Agrees with the table: members of the same populations belong to the same cultivar Same population + same cultivar = 64% + 8% = 72%

When it was used to distinguish between the main coconut cultivars, the Bayesian method used in Geneclass2 proved to be efficient in identifying coconut cultivars, even with a small sample size. This exercise became more difficult only when closely related populations were involved. In fact, the efficiency of the method depended on three factors: the sample size (both in the reference samples and in the candidates), the genetic diversity of the studied populations and the genetic divergence between populations. For this reason, larger samples are needed to study fine genetic structure on a regional scale than on a global scale. One of the important characteristics of the method is that with time, more samples can be included in the reference set, making it possible to improve its discriminating power.

Use for classification purposes

Groups of populations were compiled based on geographic origin and genetic structure. Each time when it was doubtful that a population belonged to a group, confirmation was obtained by checking that its classification remained the same when its data were excluded from the reference database. In that way, only populations MXPT2 (Mexican Pacific Tall), Colima and GGZ (one of the Gazelle Peninsula Tall samples) remained unclassified. The former case may reflect the fact that coconuts were introduced into Mexico from different countries (Zizumbo Villarreal 1996). The Colima population could result from the intercrossing between populations of Melanesian and Southeast Asian origin. On the other hand, the GGZ sample appeared to be an illegitimate accession of the Gazelle Peninsula Tall. The proposed classification is given in Annex 1.

Results

Studies using samples representing the worldwide coconut diversity were carried out using RFLP (Lebrun *et al.* 1998; Lebrun *et al.* 1999), microsatellite (Baudouin and Lebrun 2002), or AFLP (Teulat *et al.* 2000) markers. All these studies detected two major cultivar groups. The first was the Pacific group that was both the most polymorphic and the geographically most extensive. It spreads from Southeast Asia to the east coast of Latin America. It includes four sub-groups with blurred boundaries: Southeast Asia, Melanesia, Micronesia and Polynesia. The coconut palms from Panama and Peru form a fifth sub-group, related to the precedents, but clearly distinct. All Dwarfs, irrespective of their geographical origin, form a genetically uniform group that belongs to the Pacific group, sub-group Southeast Asia. The Niu Leka Dwarf is a notable exception as this cross-fertilizing Dwarf originated from the South Pacific.

The second was the Indo-Atlantic group that originated from the Indian subcontinent, from where it was subsequently transported to West Africa and the Atlantic coast of Latin America. East Africa is also populated with coconut palms of the Indo-Atlantic type, though these received an input from cultivars of Southeast Asian origin, resulting from Austronesian migrations to Madagascar.

For the most part, these results are confirmed by other studies; the distinction between the Indo-Atlantic and Pacific groups has been observed with other markers such as ISTR (Rohde *et al.* 1995; Fernando *et al.* 1997) or in a partial study carried out with RAPD markers (Wadt *et al.* 1999). The same applies for the AFLP gathered by Perera *et al.* (1998) where the main two groups were formed by local cultivars and Dwarfs of the Pacific group, along with the "auranthiaca" (King coconut and Rathran Thembili) genotypes, which actually came from ancient hybridization between the Dwarfs and local genotypes. In the study by Rivera *et al.* (1999), microsatellites showed that Dwarfs formed a uniform group within the local Talls and clearly stood out from the Pacific coconuts (RIT or Rennell Island Tall and PYT or Polynesian Tall). Minor differences exist with the RAPD study by Ashburner *et al.* (1997), which focused on the South Pacific and proposed two groups, North and South. Lastly, the classification of Florida populations by Meerow *et al.* (2003) was the only one to group the Jamaica Tall with the Panama Tall. This casts doubt on the legitimacy of the planting material used. Finally, these two groups are compatible with the results of phenotypic and polyphenol observations (Lebrun *et al*. 1999).

The contribution of microsatellites to a better understanding of coconut genetic diversity can be illustrated by comparing the resulting classification with the theory proposed by Harries (1978). According to him, all coconut cultivars were derived from two types: 1. the '*Niu Vai*' (also called 'domesticated') type, which has rounded nuts with high water content, early germination and an erect stipe and 2. the '*Niu Kafa*' (considered as 'wild' type), which have more or less triangular nuts, thick husk, a slow rate of germination and a more slender and curved stem. Many currently available coconut cultivars are intermediate between those two types. Following this typology, almost all the cultivars that tend towards the *Niu Kafa* type belong to the Indo-Atlantic group and almost all those that were considered by Harries as *Niu Vai* or introgressed belong to the Pacific group.

While concordance is the general rule, differences between these classifications are not difficult to explain: while the reasoning underlying the morphological classification mainly involves natural and artificial selection forces, the molecular classification focuses on the genetic relationships between cultivars and on their regions of origin. Due to cross pollination, Tall coconut cultivars that have grown in the same region for some time are likely to have a more or less similar genetic structure. As a result, a clear geographic pattern of variation is expected and, indeed, observed with Tall coconuts. The situation is different with Dwarfs, because they have a strong tendency to self-pollinate and tend to conserve their genetic structure irrespective of the place where they are planted. This structure therefore reflects the region where it appeared (i.e. Southeast Asia), rather than the one in which it is found, even if it has been there for a long time.

An example of discrepancy between the two classifications is the Kappadam from India. This is clearly of the *Niu Vai* type according to Harries (1978). However, microsatellites indicate that it is an Indo-Atlantic cultivar, as could be inferred from its place of origin. However, the presence of a few microsatellite markers from Southeast Asia makes it possible to understand the origin of this cultivar. Its ancestors were probably imported from Southeast Asia and strict selection was necessary to enable it to conserve its distinct *Niu Vai* traits over generations, while a large proportion of its genes have been replaced by those of the local populations, which are of the *Niu Kafa* type.

The main arguments of the theory proposed by Harries remain valid, though they do need to be moderated and complemented using molecular marker information. Considering the high diversity found in this region, the hypothesis of a centre of diversification located in the vast archipelago situated between Southeast Asia and PNG (Harries 2002) seems to be confirmed. Before its domestication, the coconut palm probably had characteristics similar to those of the Niu Kafa type, which benefited from a definite advantage for its dissemination over large distances by ocean currents. However, this selective factor was probably less important in the centre of diversification, where the distances to be covered were shorter than in the periphery. It is likely that this facilitated the appearance of the *Niu Vai* type, under the effect of domestication in Southeast Asia and/or Melanesia. In other respects, the *Niu Kafa* type predominates on the Indian subcontinent even after a long period of cultivation. Either Indian farmers had different breeding objectives from those in Southeast Asia (notably fibre production), or, despite their efforts, the populations available to them were too homogeneous to develop significantly towards the *Niu Vai* type. The counter-example given by the Kappadam suggests that the second hypothesis explains at least partly the Indian coconut palm characteristics. Moreover, this reduced diversity in the Indian sub-continent is confirmed by microsatellite markers.

There are cultivars with large and clearly *Niu Kafa* fruits in the South Pacific. The absence of obvious similarities between their microsatellite profiles and those found in the Indian subcontinent suggest that they evolved independently. During their expansion from Southeast Asia, the Polynesian ancestors might have 'rediscovered' the *Niu Kafa* type, which was very different from the *Niu Vai* types with which they had been familiar. This type was apparently maintained (and maybe accentuated by selection) due to its advantages for the production of fibres, which were valuable for navigation.

Case study: Panama Talls

The Panama Tall is a particularly important cultivar due to its place in the Pacific group and the role it plays in genetic control of Lethal Yellowing. Historical data show that it existed on the Pacific coast before the Spanish arrived (Zizumbo-Villareal and Quero 1998) and, along with the Peru Tall, it forms a group with a narrow genetic base. Five different origins of Panama Tall were compared. These were: (1) Nine PNT Aguadulce individuals (called Aguadulce IC); (2) Twenty Monagre individuals (called Monagre IC) conserved at the Marc Delorme Station in Ivory Coast; (3) Ten PNT individuals from Jamaica of 'Bowden' origin (called Bowden Jamaica); (4) Twelve PNT Aguadulce individuals from Nicaragua, of which seven displayed a typical phenotype (called Typical Nicaragua Aguadulce) and five of which were more or less atypical (called Offtype Nicaragua Aguadulce); and (5) Fifteen PNT individuals from Costa Rica sampled in Nicaragua (called Costa Rica). Four Peru Tall individuals (called Peru) were added. These 70 palms were analyzed with the 14 microsatellites in the Kit. Profiles were obtained by characterizing each individual for the 14 systems. The profiles were coded according to the number of alleles and then entered on a spreadsheet. All the samples were statistically analyzed as being individuals not attributing a priori to populations.

Principal component analysis (PCA) was used to present the distribution of population diversity in the plane corresponding to the first two components. In this PCA (see Figure 1), the populations were organized into three distinct groups: the central group contained the populations of Monagre IC and Bowden Jamaica origin, along with the Peru Tall. The resemblance between the genetic structure of the latter and that of the Panama Tall was such that these two cultivars could be considered synonymous. It implied a common origin, despite the distance separating them. The group on the left corresponds to the two populations of Aguadulce origin, which were indistinguishable using molecular markers, irrespective of their geographical provenance or their phenotypic appearance. An examination of the alleles distinguishing the Aguadulce origin from the other Panama Talls showed that this origin displayed a low percentage of genes from 'Alto Atlantico' coconut palms. This doubtless explains its greater phenotypic diversity. The Costa Rica origin forms the third group, which stands out from the central group through a few rare alleles, of unknown origin. The groupings shown here were confirmed using the Geneclass2 assignment procedure.

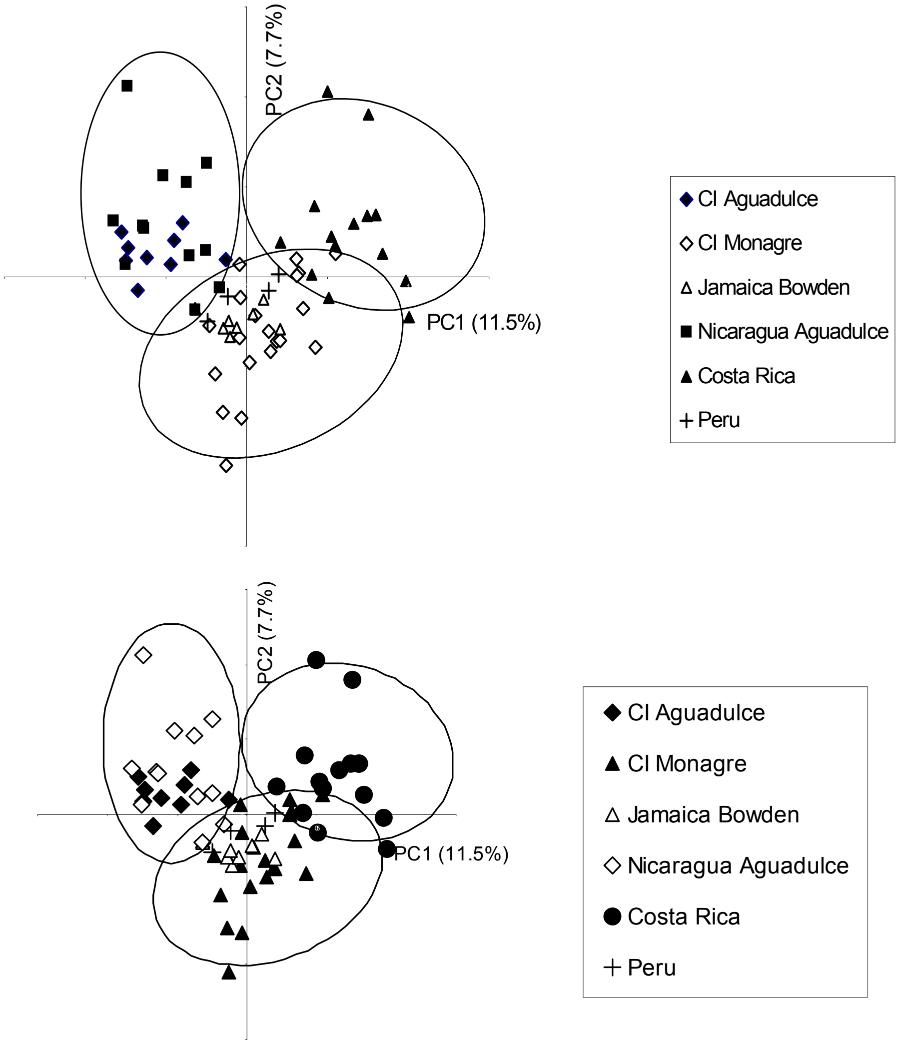

Figure 1. Distribution of population diversity of five different origins of Panama Tall along with Peru Tall

Most modern authors (Child 1974; Harries 2002) agree that the coconut palm does not originate from America, even though it has been present on that continent for a long time. This raises three questions: where did the founding individuals come from? How did they get there? When did they get there?

These three points were examined using Shannon's information theory. The resemblance between the allelic structure of the Panama Tall and that of coconut palms from different regions of the Pacific was evaluated by calculating a parameter called "ambiguity" (the less a marker provides information likely to distinguish between two origins, the greater is the ambiguity). It turned out that, despite its particular genetic structure, the Panama Tall most resembles the coconut palms of Southeast Asia, followed by that of Melanesia, Polynesia and Micronesia.

There are several arguments in favour of a Southeast Asian origin. Firstly, several plants seem to have followed the same route, including the plantain banana and bamboo. Secondly, archaeological remains dating back 2500 years, and revealing several Southeast Asian traits, have been found in Ecuador and Bahía de Caraquez (Estrada and Meggers 1961). Unlike in Panama and Peru, there is no direct evidence of a pre-Columbian existence of coconut palms in Ecuador, but if the coconut palm effectively reached America in Ecuador, it explains the existence of the same cultivar in Peru and Panama.

The Southeast Asian origin of "Bahía Culture" still arouses bitter discussions, but it nonetheless remains the case that the expansion of Austronesian peoples to Polynesia on the one hand and to Madagascar on the other hand, clearly demonstrates that those people in the remote past had the ability to undertake long sea voyages. This provides an answer to the third question raised above; the distance covered (almost 18000 km) is well beyond the possibilities of dissemination by floating on ocean currents.

Conclusion

With the microsatellite kit, molecular markers have become a powerful tool to explore genetic diversity in coconut. Although molecular markers have (in principle) no direct connections with phenotypic variation, they contribute to a better understanding of its distribution, because the distributions of characters were shaped by the evolutionary history of the populations. By combining historical records, morphological and microsatellite variation, it is possible to retrace important features of the history of the crop since its domestication. This makes it possible to understand the relationships among the cultivars found around the world. Above all, it is useful for an efficient use of genetic resources.

Managing genebanks is very expensive. For this reason, it is necessary to avoid any unnecessary duplication. By characterizing populations *in situ*, it is possible to introduce only populations with an original genetic pattern into collections. It is also possible to screen collections in order to spot possible ‘synonym’ or duplicate accessions. Such accessions do not need to be replicated further.

A second application in genebanks is to ensure legitimacy of their accessions. Plant breeding activities involve substantial resources, which can only be efficiently used if the planting material is correctly identified. If a significant number of foreign genes are found in an accession, it is worth considering resampling the cultivar. This is particularly true if the characters involved are difficult to assess, such as resistance to diseases. It was shown that some of the Panama Tall accessions display a certain percentage of ‘Alto Atlantic’ genes, irrespective of their phenotypic appearance. Illegitimacy in the parental populations could explain in part the fact that ‘Maypan’ hybrids were found to be susceptible to Lethal Yellowing. In any event, illegitimacy in disease resistance trials is likely to lead to false conclusions about resistance level.

Knowledge of genetic relationships between cultivars is also important for breeding, particularly in the framework of a global programme. It provides breeders with a way of exploiting the results obtained elsewhere. By finding the closest relative of already tested cultivars in their own collections, they can reproduce (at least in part) their useful features. One of the reasons why such reproduction may be only partial is the effect of genetic-environment interaction. Conversely, knowing the relationships between cultivars may help in predicting interactions. A good example is given by the Dwarf group, including the Marshall Green, the Kiribati Green, the Raja Brown, the Madang Brown and the Sri Lanka Green Dwarfs. In the last two, nuts are relatively large (for Dwarfs) in the Pacific Ocean, but small in West Africa. Knowledge of the genetic distance between cultivars also helps to choose right parents for hybridization, be it for producing hybrid varieties, or for the introgression of useful traits. In the first case, it was shown in Baudouin (1999) that a substantial degree of heterosis might be obtained by crossing cultivars from different molecular groups. In the second case, crossing distant cultivars will maximize genetic diversity to select from in the second and subsequent generations. Such crosses make it possible to develop the best of marker-assisted selection programmes.

Further studies on genetic diversity will be important for a clearer understanding of genetic diversity at different levels. Participatory research appraisals often lead to the identification of more coconut types than conventional ‘random’ sampling. The question is whether those types represent normal variation in the population or different genetic origins. In the efforts to find a suitable planting material policy in the presence of Lethal Yellowing, it will be important to study pathogen diversity in relation to the prevailing coconut varieties. Finally, the legitimacy test provided by Geneclass2 is not applicable for assessing the quality of hybrid seed nuts for the moment, because between-population hybrids are not in Hardy-Weinberg equilibrium. Applying suitable genetic model will require further statistical and software developments. A provisional classification of coconut cultivars is presented in Annex 1.

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Annex 1. A provisional classification of coconut cultivars

This classification is primarily based on molecular data (microsatellites). It also takes into account morphological and geographical criteria.

- There are two groups of order 1. These groups represent the major branches of coconut palm evolution, corresponding to two distinct centres of differentiation.
- In all, there are 10 groups of order 2. They represent the major divisions within the main two groups. Their name refers to the region from where the group is supposedly originated (but not necessarily the place where samples were actually taken). In the Indo-Atlantic group, cultivars are classified according to the rate of introgression by Pacific genes rather than on geographic criteria.
- There are 17 groups of order 3. They represent a more subtle division of the diversity of the species on a regional scale. This level of classification may be amended by more in-depth studies.

The molecular group is described by a code comprising three characters: capital letter for the first level, a digit for the second level and a lower case letter for the third level. (e.g. *A1a* for the southeast Asian Dwarfs, Malayan type, which belong to the Pacific group). The resulting groups are summarized in the following table. Examples of use of this classification can be found using the CGRD software.

A	**Pacific Group**		
	A1	**Southeast Asian Dwarfs**	
		A1a	*Malayan type*
		A1b	*Philippine type*
	A2	**Pacific Dwarfs (and semi-Talls)**	
	A3	**Southeast Asian Tall**	
		A3a	*Continental type*
		A3b	*Indonesian type*
		A3c	*Philippine type*
	A4	**Melanesia**	
		A4a	*North New Guinea type*
		A4b	*South New Guinea type*
		A4c	*Insular PNG type*
		A4d	*Markham Valley type*
		A4e	*Vanuatu Type*
	A5	**Micronesia**	
	A6	**Polynesia**	
	A7	**Panama (and Peru)**	
B	**Indo-Atlantic group**		
	B1	**Introgression absent to very low**	
	B2	**Low introgression rate**	
	B3	**Moderate to high introgression rate**	

Chapter 5

Germplasm use

Conventional coconut breeding

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Introduction

Coconut genetic resources have been traditionally collected and conserved in major coconut producing countries with the objective of using these to improve the genetic make up of their existing cultivars. Selected germplasm are generally used as: a) planting material to improve the coconut productivity in the country or a region; b) test material to determine the phenotypic and genotypic characters of value and c) population base for breeding superior hybrids/varieties.

Based on their origin, these germplasm could be categorized into: traditional varieties or landraces, as exotic varieties introduced into the country, or as modern varieties or hybrids resulting from a national breeding effort. Most coconut producing countries have a mixed population of landraces and introduced hybrids/varieties. There are continuing efforts to further improve cultivars through mass selection and hybridization, and to produce synthetic varieties for economic reasons.

As breeding material, the coconut germplasm are generally grouped according to their growth habit. In addition, the differences in their mating behaviour give the breeders flexibility in designing various breeding schemes to achieve their desired coconut ideotypes. The STANTECH manual (Santos *et. al* 1995) described the following major classification of coconut:

1. **Tall palms**, sometimes referred to as var. *typica* (Nar.), are essentially cross-pollinating and therefore considered to be heterozygous. They are slow maturing and flower 6-10 years after planting, and can grow to a height of 20-30 m. They have an average economic life of 60-70 years.
2. **Dwarf palms,** sometimes referred to as var. *nana* (Griff.), are normally self-pollinating and therefore considered to be homozygous. They are believed to be mutants from Tall types with short stature, 8-10 m when 20 years old. They begin bearing about the third year sometimes at less than 1 m stem height but have a short productive life of 30-40 years.

There are also rare 'intermediate types' which do not express the phenotype normally associated with either the Talls or the Dwarfs. Natural crosses between Tall and Dwarfs occur sporadically in traditional populations. In some instances, such open-pollinated hybrids may become fixed as 'semi-Talls', which have the same mating behaviour as Dwarfs but grow faster. In the South Pacific, there is also a Niu Leka Dwarf, which has all the characteristics of a Tall type coconut, except for its short stature. These intermediate types have a good potential in broadening the genetic base of the breeding population but their parental value has yet to be fully evaluated.

This paper presents the various ways these coconut germplasm are used in conventional breeding, the general status of the breeding programmes for coconuts including their limitations and constraints, and future breeding strategies.

Population base

The coconut (*Cocos nucifera* L.) is a diploid with 32 chromosomes (2n=32) and the sole species of the genus *Cocos*. As such, current breeding work on this tree crop is limited to the intraspecific level.

The coconut palm is monoecious, i.e. its inflorescence carries both staminate (male) and pistillate (female) flowers (Frankel and Galun 1977). Generally, Talls, being protandrous, shed pollen prior to stigma receptivity. They are generally considered as allogamous. Nevertheless, selfing is possible because of the variable overlapping between the female phase of an inflorescence and the male phase of the next inflorescence. The speed of emission of inflorescences varies according to genotype and environment, with a great seasonal variation; so do the selfing rate. On the other hand, the Dwarfs are generally considered homogamous as stamens and pistils mature simultaneously thus Dwarfs can shed and receive pollen at the same time resulting in inbreeding. Apart from their short stem, most of the Dwarfs show a combination of common characteristics: preference to autogamy, sensitivity to environmental stresses, small-sized organs, precocity, and rapid emission of inflorescence. Because of the last three characteristics, the Dwarfs play an important role in hybridization programmes. However, the genetic determinant of coconut dwarfism is still unknown.

The bisexual nature of the Talls and the Dwarfs allow manipulation of pollination to secure the desired level of genetic introgression with the Talls as source of heterozygous genotypes while the Dwarfs provide the progenitors of homozygosity.

The genetic structures of coconut are yet to be fully understood, and the diversity of identified and collected coconut germplasm are yet to be fully exploited. As of 2003, the Coconut Genetic Resources Database

(CGRD) of the International Coconut Genetic Resources Network (COGENT) listed 599 Talls, 111 Dwarfs and 1 semi-Tall cultivar plus few cross- fertilizing Dwarfs (Hamelin 2003). However, a total of 1416 accessions are entered into the CGRD of which less than 5 % (<60) are actually being used as parents in national breeding programmes of the COGENT member countries as revealed by COGENT country surveys in 2001-2003. These also revealed that the more popular parental accessions for hybridization were the West African Tall (WAT), Rennell Island Tall (RIT), Vanuatu Tall (VTT), Malayan Yellow Dwarf (MYD), Malayan Red Dwarf (MRD), Malayan Green Dwarf (MGD) and Cameroon Red Dwarf (CRD). According to Bourdeix (1999), before 1993, about 400 coconut hybrids were created around the world in national research programmes; however, less than 10 of these coconut hybrids have been tested internationally under various ecological conditions. Recently, COGENT has tested 34 promising hybrids in three African (Benin, Côte d'Ivoire and Tanzania) and three LAC countries (Brazil, Mexico and Jamaica) to test their agronomic performance and their Germplasm x Environment interaction (see Batugal *et al.* in Chapter 5). The availability of characterization data (quantitative and qualitative descriptions of major traits) on most of the catalogued accessions of the CGRD, and the establishment of the International Coconut Genebank (ICG) and national genebanks (28 genebanks in 24 countries), there are now new options for breeders to incorporate more accessions into their breeding schemes.

The patterns of genetic differentiation for many of the available coconut accessions are being determined at the morphological and molecular levels (see related articles in Chapters 4 and 5). Initial results showed close relationship between some accessions which helps to avoid the use of 'duplicates' in breeding programmes. Some cultivars such as the Malayan Tall and Pakistan Tall (represented by 49 and 32 accessions, respectively) are described very often in the CGRD (Hamelin 2003). Similarly, there were 31 accession entries of East African Tall reported from Tanzania and five from India. Obviously, the same genotype may carry different accession codes/names depending on the source of origin or collecting site.

In many small coconut producing countries, breeders accessed germplasm not necessarily for breeding purposes but to select genotypes for direct release as varieties. The selection process is usually done through on-farm varietal evaluation with the traditional cultivars serving as basis of comparison or control. This provides a short cut to the long and tedious process of undertaking a hybridization programme, which in coconut usually takes 14 to 15 years, just to produce and evaluate a single generation of progenies. Nevertheless, this type of short-term selection inhibits further work towards maximizing heterosis that only a well-designed breeding programme could achieve.

Although coconut is a monotypic, the genetic variability that is present in the current collections is sufficiently broad for the breeders to undertake various breeding schemes in developing improved coconut varieties. The existing variable traits between the Tall and Dwarf populations and within the Talls provide a good opportunity to produce various recombinants that could yield the desired characters. It is only through actual germplasm use, such as in conventional breeding, that the continuing activities on collecting, maintaining and characterizing of coconut germplasm could be justified.

Conventional breeding schemes

Mass selection methods

Three options of mass selection exist, according to the choice of a reproductive system: mass selection using open pollination, selfing or intercrossing.

Mass selection using open pollination has been the mostly practised method. The main advantage of this method is its simplicity; the seednuts are collected from palms that present attractive characteristics at a time. The progenies resulting from open pollination are the basis of an improved population which will then undergo other selection cycles. In the case of coconut, the efficiency of mass selection using open pollination has been the subject of a harsh controversy (Bourdeix 1988). Divergent results were obtained, partially because of the natural reproductive system of the Tall palms. Although Talls are mainly allogamous, selfing remains possible. The rate of selfing increases with the speed of inflorescence production. Best palms on best plots produce more inflorescences so they may have a higher selfing rate than others. Their progenies will suffer from an inbreeding handicap. The speed of inflorescence emission also varies strongly between seasons. Therefore, selection results will differ according to the season within which seednuts are harvested. Although there was a positive response to the selection, the best result obtained was at most a 14.4% gain in the first generation from a selection of 5% best palms (Liyanage 1972). The severe selection required for obtaining a genetic progress limits seednut production capacity.

For the coconut palm, the effectiveness of the mass selection using selfing seems to be limited. A single generation of selfing in a Tall coconut population generally causes a decrease of fruit production of about 15 - 25 % (Bourdeix 1999). Obtaining pure lines from heterozygous Talls remains a long-term prospect which “would discourage the most ardent”

(Charles 1961). The four generations required to create 95% homozygous structures represent a period of 25 to 60 years, depending on the method of parent evaluation.

Mass selection using intercrossing has never been evaluated for coconut. The principle is to select parent palms on the basis of their phenotypic performances and to intercross them. Various crossing schemes can be followed, such as independent pairs and factorial crosses. Forty to fifty mother trees can be pollinated with the pollen of a single male parent, allowing for a stricter selection among the male parents. One could retain 10-20% of the population as mother palms and use a selection rate of less than 1% for the male parents.

The three mass selection methods can be ranked by increasing efficiency: selection using selfing, open pollination and intercrossing (Bourdeix 1999). The first two methods are of limited effectiveness. Selfing induces a yield decline without appreciably increasing production homogeneity. Open pollination leads to variable results, due to absence of control on pollen origin. Mass selection using intercrossing appears theoretically more effective, as it allows for a strict selection of pollinators while retaining a large potential of seednut production. However, there are no experimental results available that make it possible to assess the genetic progress that could be realized with this last method.

Other intra-population breeding methods

These methods based on progeny testing within a given population were occasionally applied to a few Tall varieties located in Indonesia, Sri Lanka and India. Harland (1957) introduced the concept of 'prepotent palms' as mother palms, which in spite of having indiscriminately pollinated by miscellaneous males possess sufficient dominant yield traits to pass on to their offspring. Later, Satyabalan and Mathew (1983), using modern breeding concepts, argued that 'prepotent palms' are nothing more than palms with good general combining ability. Since evaluating coconut progenies is time consuming and laborious, attention was diverted to the possibility of identifying so-called 'prepotent' palms from their progeny at seedling stage (Nampoothiri 1991). Many researches, especially from India, are studying the correlation of seedlings characters with adult palms.

Single cross hybrids

As mentioned above, the current base populations of breeding programmes for coconut generally consisted of selected Talls and Dwarfs. A parental genotype is usually selected based on its proven performance in the areas of intended use, such as nut, copra or oil production. The other parent is usually chosen because it complements the specific weakness of the first parent, such as precocity or resistance to biotic and abiotic stresses. Preferred major traits of a Tall parent are high productivity, broad adaptability and tolerance to specific pests and diseases. Dwarfs are preferred for their precocity and high rate of bunch emission (Bourdeix *et al.* 1998).

Unlike in most annual crops where selected parents are first developed into inbred lines to produce uniform progenies, most coconut breeders practised straight forward parental selection based on combining ability tests and/or on previously reported performance or traits from the source of origin. This is due to the very long-term nature of purifying the parental lines and producing a generation of progenies. The most popular scheme of improving coconut cultivars is through hybridization of parents with exceptionally good combining ability. When hybrid varieties are feasible, they make better use of heterosis than any breeding procedure yet developed (Allard 1960).

The most common types of commercial coconut hybrids are single crosses between Dwarf and Tall (D x T) and between unrelated lines of Tall populations (T x T). Single crosses are believed to provide the greatest opportunity for expression of hybrid vigour and usually have higher yields than other types of hybrids (Wright 1980).

Most breeding programmes of the COGENT member countries prefer D x T hybridization (Table 1) because of the ease of pollinating the mother palm due to its shorter stature and due to the relative precocity of the resulting hybrid. However, this requires careful emasculation of the Dwarf parent to prevent self pollination. The possibility of finding male-sterile and self-incompatible lines among the Dwarf populations has yet to be explored in coconut. The reciprocal T x D crosses were earlier done in India, Papua New Guinea and Nigeria largely to determine the general and specific combining abilities of the parental lines for specific traits (Batugal and Ramanatha Rao 1998).

Traditionally, the T x T breeding scheme is practised in most coconut producing countries through a formal breeding programme or as a result of natural outcrossing among and within the Tall populations. Using genetically distant ecotypes, the principal effect of hybridization is the increase of the frequency of heterozygous genotypes that could enhance artificial selection towards the desired traits. Open-pollinated palms from selected Tall parents with outcrossing behaviour would similarly exhibit hybrid vigour and could be naturally produced in isolated gardens with the help of wind, insects and other pollen vectors.

Comparing D x T and T x T, initial country reports showed that D x T hybrids generally outperform the inter-Tall crosses. D x T could be considered a wider cross than the inter-Tall crosses and hence, expectedly have higher genetic variances and overall population means. However, Bourdeix (1998) reported that in the long term the T x T can have a cumulative production equivalent to the yield of D x T as demonstrated in the comparison between the WAT x RIT improved hybrid and the PB121 (MYD x WAT) at the 9th year of production cycle. Later, it was reported that the T x T hybrid even outyielded the PB121. Similarly, Santos (2001, unpublished) observed that after 15 years, the yield of the Philippines' local Talls, such as Tagnanan Tall and San Ramon Tall, could equal the yield of D x T hybrids and that the superiority of these hybrids appeared to be only in the first 12 years. Apparently, it would take several production cycles to fully assess the comparative advantage of the different conventional breeding schemes for coconut.

The D x D hybridization technique is not very popular among the coconut breeders. Dwarfs are reputed sensitive to environmental stresses, such as drought and low fertility soils. Nevertheless, some of the most profitable coconut plantations in the world are probably those of Green Dwarfs found in Brazil and Thailand; with high planting density (more than 200 palms per hectare), high fertilization rate and sufficient irrigation. The Thailand coconut breeding programme is now mainly focused on the improvement of the Aromatic Green Dwarf varieties. An experiment was conducted in Côte d'Ivoire in 1971 to test the three possible hybrids between MYD, MRD and Brazil Green Dwarf (BGD) and compare them with MYD as control (Le Saint and Nuce de Lamothe 1987). The hybrid MYD x MRD produced an average of 3.8 tonnes copra per hectare which was comparable to the production level of a good D x T hybrid. An important feature of D x D hybrids is their high genetic homogeneity. As the two Dwarf parents are close to pure line, their progenies are less likely to be variable in genotype than the D x T and T x D hybrids.

Some of the best D x T and T x T hybrids were improved using the individual combining ability tests method and by exploiting the genetic variability that exists within the populations of Talls. For a description of this method, it is better to use an example. The hybrid PB121 is a cross between the MYD and a selected population of WAT. Its good performance in Côte d'Ivoire has stimulated its further improvement. Forty-five WAT parent palms were selected based on phenotype and individually crossed with the same MYD population. The 45 progenies thus obtained are considered half-sib families. In only one generation of breeding, it was possible to improve the yield of the earlier PB121 hybrid from 15 to 25 percent; some of the improved F_1 progenies were also proven to be more tolerant to the *phytophthora* disease in Côte d'Ivoire (Bourdeix *et al.* 1992). This method, initially developed by CIRAD in the 1970s, was applied mainly in Côte d'Ivoire and Vanuatu on D x T and T x T hybrids using the West African, Rennell Island, Tahiti and Vanuatu populations of Talls.

Complex hybrids

In breeding coconut, promising hybrid progenies are identified, evaluated and selected for specific traits as early as in the F_1 generation. This, of course, limits a complete exploration of possible polygenic recombination of a cross. Few countries are currently testing multiple crosses to develop varieties with desirable multiple traits or simply carry on the selection process to the next steps.

Thailand is testing 3-way cross hybrids (TxT) x T and (DxT) x T. It will be interesting to compare the level of heterogeneity of these two kinds of combination. Because of segregation for dwarfness, (DxT) x T will be probably more variable than (TxT) x T, but this remains to be studied.

In Côte d'Ivoire, as early as 1976, the MYD was crossed with the hybrid WAT x RIT. This 3-way hybrid, planted in medium agronomic conditions, yielded only 77% more than the WAT control. In other better experiments, the single cross hybrids MYD x WAT and MYD x RIT yielded 97% and 129% more than the WAT control, respectively (Anonymous 1988). Nevertheless, in Côte d'Ivoire, Dwarf varieties are now systematically crossed with a tester made of selected parent palms from the hybrid, WAT x RIT. Also in Côte d'Ivoire, from 1986 to 1992, double or 4-way cross hybrids were also created: (DxT) x (DxT), (DxD) x (TxT) and (DxT) x (TxT) using selected Tall and Dwarf progenitors. However, these were not included as a part of the main classical breeding scheme. They were specially conceived anticipating the possible development of a cloning technique.

Synthetic varieties

In addition to the hybridization method of improving coconut cultivars, the Philippines is spearheading the development of synthetic varieties which are predicted to have wider adaptability and stability in performance due to the utilization of several selected parents as compared to single cross hybrids (Santos and Rivera 2002). The parental base of a synthetic variety is a composite of selected parental lines which combined well in all combinations through natural crossing. Hence, prospective parental genotypes are first tested for their combining ability or additive gene effects before they are entered into the mating pool. Accordingly, the most critical stage in the development of a synthetic variety is the selection of the parents for the composite. In corn, the expected yield of the Syn_2 increased steadily as inbred lines with higher combining ability were added, reaching a maximum at 5 or 6 parental lines, after which the expected yield decreased steadily as more lines were added (Allard 1960). To summarize, finding the optimal number of parental lines requires a trade off between the selection of best lines, which tends to reduce this number and reduction of consanguinity, which tends to increase it. In coconut, the main drawback in developing synthetic varieties is that the combined genes favouring the desired traits may only attain equilibrium after several cycles of intermating since inbreeding or purification of parental lines are generally circumvented.

An important question related to the use of synthetic varieties is that seednuts released to farmers are obtained from open pollination. Therefore, the same problem may arise as described in the mass selection process. Selfing rate varies with the speed of emission of the inflorescences, depending on genetic and environment factors, and is very sensitive to seasonal effects. As there is a strong inbreeding depression, the mean values of the seednuts may vary with seasons. This could be avoided by removing the 'unwanted' inflorescences in the seed gardens at the critical seasons. This way, the possibility of natural selfing will be eliminated and the mean value of seednuts will increase and become homogeneous.

Status of coconut improvement

Breeding goals. In general, the short-term goals of most coconut producing countries are designed to develop varieties and hybrids based on their target ideotypes. Their intermediate- and long-term goals include characterization and development of materials that have potential in future breeding programmes. Coconut breeders are understandably concerned with and more focused on short-term goals. Although the improvement of breeding populations and conservation of genetic variability are important long-term goals, the resource requirements for such undertaking are mostly beyond the capability of national coconut breeding programmes. Hence, as a complementary effort, COGENT established the International Coconut Genebank (ICG) in 1997 to pursue these long term goals. There are four regional ICGs based in: Indonesia for Southeast Asia, India for South Asia, Papua New Guinea for the South Pacific and Côte d'Ivoire for Africa and the Indian Ocean (Ramanatha Rao and Batugal 1998).

Breeding results. Despite the limitations on breeding, resource and time investments, coconut breeders have been successful in developing varieties and hybrids for environments in which they were grown. Table 1 shows the types and number of promising and/or recommended single cross hybrids in major coconut growing countries. The D x T hybrids obviously dominated the breeding output, followed by the T x T progenies. Promising T x D and D x D crosses were reported only in India and Fiji, respectively; although Côte d'Ivoire has already produced exceptionally high yielding MYD x MRD hybrid as early as 1971.

Table 1. Types of promising/recommended (single cross) hybrids in selected coconut growing countries
*(Sources: *P Batugal 2004; **P Batugal and V Ramanatha Rao 1998)*

Country *	Types and number of hybrids			
	D x T	T x T	T x D	D x D
Benin	2			
Côte d'Ivoire	6	2		
China	1			
Fiji	3			1
Ghana	2			
India	1		3	
Indonesia**	3	4		
Mexico	4			
Philippines	7	3		
Papua New Guinea	15			
Sri Lanka	1	2		
Tanzania	14	5		
Thailand	2	1		
Vanuatu	1	1		
Vietnam	3	3		
TOTAL	**65**	**21**	**3**	**1**

In terms of breeding for resistance to biotic and abiotic stress, the infusion of resistant genes is done by intercrossing stress-tolerant germplasm with adapted germplasm. Some of the known cultivars being used in breeding for major coconut disease resistance are: Vanuatu Tall for tolerance to coconut foliar decay, Pacific Tall and Malayan Dwarf for lethal yellowing disease resistance and Sri Lankan Green Dwarf for Cape St. Paul wilt tolerance. Rajagopal *et al.* (Chapter 5) reported that in general, Talls and hybrids with Tall as mother palm have higher drought tolerance compared to Dwarfs and hybrids with Dwarf as mother palm. Most drought tolerant varieties have thick leaflets and thick cuticle. In addition to anatomical feature, the behaviour of coconut varieties on drought is influenced by environmental physiological and biochemical factors.

Technology gap. Comparing the national yield average in farmers' fields and those of research stations in 15 coconut growing countries, the estimated technology gap in terms of nuts and copra yield ranged from

33 to 84% (Table 2). The significant improvement in productivity at research stations could be attributed to using hybrids/improved varieties in conjunction with proper management and cultural practices. The low productivity in farmers' fields could be due to poor cultural management/ lack of production inputs and the use of poor quality planting materials.

Table 2. Coconut productivity in farmers' field and research stations, and area planted to hybrids
(Source: P Batugal and J Oliver, 2003)

Country	Yield per Year: (A) Farmers' Fields/National Average Nuts Copra (t ha^{-1})	Yield per Year: (B) Research Station/Hybrids Nuts Copra (t ha^{-1})	Technology Gap [100-(A/B x100)]	Area grown to Hybrids (% of Prod'n area)
South Asia				
Bangladesh	21/palm	69/palm	70	nil
India	6892/ha	23 700/ha	71	14
Sri Lanka	42/palm	63/palm	33	11
Southeast Asia				
Indonesia	1.1	3.5	69	5
Malaysia	10 000/ha	23 000/ha	57	n.d.
Philippines	0.78	4-6	84	n.d.
Thailand	1.2-1.5	3.0	55	10
Vietnam	38-40/palm	55-80/palm	42	<0.1
South Pacific				
Fiji	0.3-0.5	2.0	80	<5
PNG	0.66	2.8-3.6	80	
China	1.27	3.6	65	1.5
Africa				
Ghana	20/palm	n.d.		3
Tanzania	40/palm	80/palm	50	n.d.
LAC				
Jamaica	0.8	3.7	78	n.d.
Mexico	0.65	4.0	84	1

Although hybrids generally performed better than the traditional varieties, they are currently being grown in limited areas, less than 0.1 (or even nil) to 14% of cultivated coconut farms in various countries (Table 2). The poor adoption of hybrids may be attributed to inadequate information dissemination on the availability of improved hybrids/varieties and lack and affordability of planting materials. Those who planted hybrids, mostly favoured D x T and T x D for their high yield, early bearing, good nut size and better resistance to pests and diseases (Rethinam *et al.*, Chapter 5). However, some dissatisfaction on these hybrids was expressed in terms of bunch buckling, high input requirement, vulnerability to moisture stress, and pests and diseases.

Breeding limitations and opportunities

The primary breeding procedure in coconut continues to be single-cycle selection due to its 9-10 year production cycle, excluding the breeding and evaluation phases. This is a limiting factor because selection, when done in early generations, fails to consider undesirable linkages that may occur between qualitative genes and genes for quantitatively inherited traits (Halluer 1981). It takes time for recombination to break up these allelic associations and release the latent genetic variation (Falconer and Mackay 1996). For perennial plant like coconut, molecular marker techniques would enhance the efficiency in locating diversity during collecting activities and in characterizing diversity to eliminate duplicates in the genebanks (Batugal 1999). The technique would require finding specific markers that could highly predict the progenitor's value. Individual selection could then be done even at embryo stage as long as molecular markers are manifested. In potato (Peloquin 1981; Khwaja *et al.* 1986), the use of 2n pollen as a marker eliminated the need for field testing of diploid species which may be compatibly crossed with the cultivated tetraploids. In coconut, marker-assisted selection is currently limited to partitioning the genetic distance between and among populations (see Chapter 4). An early growth marker (molecular or morphological) with strong correlation with desirable traits would translate to significant savings on time, space and cost of breeding coconut.

Another major limitation in breeding coconut is the long and expensive process of propagating the selected progenitors. The use of embryo culture may facilitate the rapid and safe propagation of breeding materials with the development of viable protocols (Batugal and Engelmann 1998; Engelmann *et al.* 2002). The ICG is promoting the use of *in vitro* cultured embryos to save on cost and facilitate the safe movement of germplasm accessions. In the past, somatic embryogenesis has been tried to increase propagation efficiency. However, the recovery rate of somatic embryos and *ex vitro* seedlings in the nursery had been very low, making it an expensive proposition. Recent findings at the EXPAND (PALM2LINK) conference in Manila (Oropeza *et al.* 2004) indicate significant progress and increased recovery rates, enhancing the potential of somatic embryogenesis for reducing the cost of propagating improved varieties and hybrids both for breeding and for replanting.

A procedural limitation in breeding coconut is the artificial or hand pollination of mother palms which requires substantial human and financial resources. Unlike the protandrous populations which can naturally be crossed in isolated gardens, production of hybrid progenies requires the tedious process of artificially emasculating and pollinating the mother palms. Identification of cultivars that exhibit sexual characteristics different from the norms due to environmental or other mutagenic conditions would allow manipulation of pollination for breeding purposes. Self-incompatible or male sterile lines to facilitate hybridization in otherwise self-pollinating plants are commonly practised in many annual crops. Thus, a careful search for male-sterile coconut palms could prove useful.

Considering the substantial number of coconut accessions conserved *in situ* and *ex situ* worldwide, the available genetic variability for breeding manipulation is tremendous but hardly used. Current breeding programmes are using very few of these available germplasm. The main problem appears to be the lack of complete characterization (morphological, physiological and molecular) of most of the conserved germplasm which would give an indication of their potential as breeding materials. Only a little over half of the accessions listed in CGRD have values for 25% to 50% of their passport and assessment descriptors. Hence, COGENT is generating more support to maximize characterization work of *ex situ* conserved germplasm.

Largely untapped are landraces or farmer varieties which are yet to be fully collected and conserved in genebanks. Landraces may generally be characterized by their high levels of heterogeneity compared to modern commercial cultivars, comparative stability across seasons, location specificity and generalized, rather than highly specific, tolerances and resistances (Hawtin *et al*. 1997). These landraces actually evolved through generations of simple mass selection by coconut farmers. Hence, farmer-participatory approach to characterizing the traditional cultivars and *ex situ* conservation of promising populations could significantly facilitate the utilization of landraces for breeding efforts. COGENT has recently developed a protocol for farmer characterization of coconut varieties to secure indigenous information on landraces.

Farmers' varietal preferences

The survey on the performance of high-yielding hybrids and varietal preferences conducted by APCC through the financial support of APCC, BUROTROP and COGENT (see Rethinam *et al.* in this chapter) indicated the following: 1) there is no universal hybrid; 2) hybrids perform better than traditional Tall varieties under good rainfall and soil conditions; 3) several farmers prefer traditional Tall varieties to hybrids because of various reasons. The reasons could include that the Tall varieties may be well adapted to their cultural and traditional practices, and perform better under low fertility and high abiotic stresses. For example, in the typhoon that hit Fiji in January 2003, only about 20% of the traditional Talls were damaged compared to about 80% of the Dwarfs and D x T hybrids. In Comoros Islands, roofs and fences made with coconut foliage of Tall varieties last longer (two times longer) than those made using D x T hybrids leaves. Many farmers wish to sow both Talls and Hybrids.

Under COGENT's current ADB-funded 'Development of sustainable coconut-based income generating technologies project', farmers have identified some varieties that have traits suitable for the production of high-value coconut products. Based on the above, breeding programmes should be designed to develop and provide either varieties or hybrids that suit specific agroecological conditions and small-scale farmers' needs. In the end, each national coconut breeding programme should be able to propose to farmers a set of well-evaluated varieties including Dwarfs, Talls, and Hybrids.

Future breeding plans

Barring any breakthroughs in genetic engineering, the conventional breeding approaches would remain to be the major methods of utilizing coconut germplasm. In view of this, COGENT is proposing a globally coordinated breeding programme for coconut to facilitate the use of available germplasm worldwide and expedite works on developing improved varieties. The breeding programme shall focus on the global/regional needs of COGENT member countries instead of merely those of individual countries and will adopt participatory plant breeding approach to incorporate farmers' varietal preference.

Specifically, the programme initially aims to: 1) characterize conserved germplasm and farmers' varieties using morphometric and molecular techniques; 2) screen and identify ecotypes tolerant or resistant to the lethal yellowing disease and drought; 3) improve yields for specific uses and adaptation; 4) develop varieties which are suitable for the production of high-value products from husk, fibre, shell, meat, water, wood and leaves; 5) develop technical support systems for national breeding programmes (i.e. information, pollen and embryo provision, etc.); and 6) provide a platform to promote the dissemination and use of the results of the above-mentioned coconut breeding projects to achieve socioeconomic and environmental impact. Ultimately, the programme should be able to significantly increase the choice of hybrid cultivars among coconut growing countries, by maximizing the use of available genetic resources for breeding purposes, and improving the quality of the planting materials for distribution to users or farmers.

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Use of molecular markers for coconut improvement: Status and prospects

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Introduction

Some characteristics of coconut are significant for understanding the constraints and the limitations affecting coconut breeding efficiency:

- It is a tree crop; it has a long life cycle and needs to be observed for several years after sexual maturity, which is reached from 3 to 6 years after field planting. As it is planted at a low density (typically between 140 to 200 palms/ha), genetic trials require large areas.
- It exhibits a large phenotypic diversity from Dwarf to Tall with various intermediate forms. This variability is especially obvious on fruit characters;
- Although Tall cultivars are mainly cross-pollinating, self pollination occurs at a rate that is strongly determined by the environment. Dwarf cultivars are mainly self-pollinated, but not strictly so and Green and Brown Dwarf types often show a certain percentage of cross-pollination;
- It is subject to severe inbreeding depression but may also show high interpopulation heterosis;
- It has a low multiplication rate: in very good conditions it may produce 100 descendants per year only; and
- There is no horticultural vegetative propagation method for coconut and there is no routine *in vitro* vegetative propagation technique.

Seeds for the propagation of coconut are produced by different methods and these include:

- Collecting seednuts in farmers' fields from 'informal' local cultivars;
- Collecting seednuts in research stations or high yielding blocks from 'improved' local cultivars with selected, open-pollinated parents;

- As a variant of the above, collecting seednuts from open-pollinated synthetic variety;
- Seed production in Dwarf x Tall hybrid seed gardens; and
- Seed production in Tall x Tall hybrid seed gardens.

In addition, the trend toward multipurpose uses of coconut is on the increase, which further increases the selection criteria for nut production.

From the above it can be seen that the use of molecular breeding techniques would help in dealing with some of the complexities of coconut breeding. The long life cycle, bulkiness and low rate of multiplication make 'conventional' breeding costly. Identifying molecular markers linked to useful traits and characters is expected to strengthen and speed up breeding, while reducing costs, improving efficiency and reducing the length of the selection cycle. This paper, discusses the different molecular tools that can assist in plant breeding and examines their application to coconut improvement.

Potential for success in molecular breeding in coconut

In general, the use of molecular marker may improve breeding efficiency in different ways: germplasm characterization and management (see Lebrun *et al.*, Chaper 4); linkage mapping and identification of quantitative trait loci (QTL) markers for marker- assisted selection (MAS); identification and physical mapping of genes with known function; and introduction of functional genes into the genome of an individual. Below is a brief discussion on how these different applications could be useful in plant breeding.

Linkage mapping and marker-assisted selection

Dekkers and Hospital (2001) did a comprehensive review of the molecular methods used in the improvement of plants and animals. When ordered on a linkage map, anonymous markers can be used to identify chromosome regions where the QTLs are located. Typically, the precision of the location is about ±10 centimorgans (cM). In principle, there is no functional relationship between the markers used and the actual QTL. They serve only as 'labels' for the QTL: by selecting markers surrounding the favourable allele QTL, this allele is also selected (unless a double recombination occurs in the corresponding interval) and, thus, the desired trait is improved. Various strategies are available to exploit this knowledge: genotype building programmes that consist of assembling the favourable alleles of many QTLs in a single genotype; introgression programmes that are used to introduce the favourable allele of a specific QTL into an otherwise good variety; recurrent selection programmes that can use molecular score in addition to phenotypic data to predict the value of parents.

Molecular breeding efficiency is at its best with traits exhibiting a moderate heritability, as identifying QTL's markers requires that some genetic variation is observable, while conventional breeding gives satisfactory results with highly heritable traits. Two additional factors are important for the success of MAS compared to conventional breeding. Firstly, close linkage between the markers and the actual QTL is necessary, especially if their association is to survive several recombination cycles. This underlines the need to fine map QTLs wherever possible. Secondly, the higher the percentage of additive genetic variance accounted for by the identified QTL, the higher will be the efficiency of MAS. It must be noted, however, that the efficiency of MAS is often overestimated. This is due to the limited precision of the QTL's location, to its association with unwanted (and unnoticed) unfavourable traits and to epistasis effects or genotype x environment effect. The initial enthusiasm about molecular breeding has thus been tempered with 'cautious optimism'.

As genotyping is still expensive, the cost/benefit ratio of molecular breeding needs to be considered. Situations that are favourable to the use of molecular breeding are mainly those where the target trait is difficult to assess (or cannot be assessed at each breeding cycle) like disease resistance, when the measurement is expensive or time consuming. In the case of coconut, most of the traits related to nut production and quality require several years of observation after sexual maturity. The main expected benefits of MAS in coconut are saving time (by selecting, based on markers only, at an early stage) and space (by combining marker selection in nursery with phenotypic selection on the selected genotypes) in breeding programmes. Both factors are critical for coconut improvement.

Synteny

The above approach requires extensive mapping of the species genome because nothing is assumed about the location of interesting QTLs. Its efficiency may be improved if some information about the location and function of QTLs is available, even from another species. This information may come from a related species, where some QTLs have already been identified. By establishing a correspondence between the two species' chromosome maps (using markers that are polymorphic in both species), it is possible to check in species A for the presence of a QTL that has been identified in species B. Application of this principle has been demonstrated for sorghum and sugarcane (Dufour *et al*. 1997), for rice and sorghum (Ventelon *et al*. 2001) and also for a group of species including rice, sorghum and maize (Asnaghi *et al*. 2000; Glaszmann *et al*. 1997). The similarities between large fragments of the genome in these three species made it possible to locate a gene for rust resistance in sugarcane. Oil palm is the closest, economically important species, related to coconut. It is anticipated that relatively large parts of the genomes of these species are colinear (i.e. large blocks of genes are ordered in the same way). A total of 915 markers have already been placed on a saturated oil palm linkage map, based on 116 progenies, of which 257 are microsatellites (including 20 markers from coconut), the remaining being AFLPs (amplified fragment-length polymorphism). Twenty four traits, related to yield, quality of oil and vegetative development were observed and about 30 putative QTLs have already been located.

Candidate-gene approach and physical mapping

While synteny exploits the conservation of large portions of the genome in closely related species, the candidate-gene approach exploits the conservation of the genetic structure of functional genes or groups of genes in unrelated species (sometimes, in different reigns). This reflects the fact that the genes, whose function is necessary for the development and for the survival of the organism (i.e. producing a structural protein, an enzyme or a regulating factor), are subject to natural selection. Thus, their sequences are much more conserved than that of non-coding parts of the genome. For this reason, similar genes, with often the same function are found in very distantly related species. Looking for the presence of sequences related to known metabolic functions might be a first step for characterizing potential QTLs and for locating precisely the genes involved. For example, a eukaryotic translation factor is found to be associated to virus resistance in pepper (Ruffel *et al*. in press).

This approach requires knowledge of the fine structure of the genome and a physical mapping of the chromosomal region involved (Han *et al*. 1999). The bacterial artificial chromosomes (BAC) are long DNA sequences that make it possible to construct precise ‘physical maps’ (i.e., based on sequence length measurement rather on recombination rates). A BAC library of coconut exists at CIRAD and its total length is five times that of the coconut genome. Theoretically, this ensures that a little less of 1% of the coconut genes are not represented in the library. In practice, it may be a little more, as the sequences included in the BACs are not exactly a random sample of the genome.

The possible applications of such an approach in coconut include search for candidates for resistance genes to pathogens. Actually, candidate gene and physical mapping are not breeding methods, but rather tools that can be exploited through MAS or through genetic engineering. In addition, it should be noted that large mapping populations (about 800 individuals) are necessary to take the full advantage of such approaches.

Genetically-modified organisms

Genetic transformation consists in introducing a gene (from the same species or from another species) into the genome of an organism. After its introduction, this gene functions as a part of the recipient plant genome and may be transmitted sexually. Genetic transformation involves several steps:

- Setting up a genetic construction (a chimerical sequence of DNA), generally including the desired gene a promoter to control the gene expression; and sometimes, a 'selected' gene use for identifying and selecting the transformed plants.
- Introducing the construction into the plant cells (several methods are available).
- Selecting the plants that have included the construction in their genome and thus express the 'selected' gene.
- Checking that the transformed plant behaves as expected.

There are several applications of genetic transformation in plants and may include the following objectives:

- Production of plants adapted to environmental stresses, like drought or resistant to pests or diseases.
- Production of substances with insecticidal properties in its leaves, or by introducing resistance to a herbicide into a plant to help reduce the cost of crop maintenance.
- Alteration of the chemical composition of the product- for example, modified oil composition, with increased lauric acid content for canola, production of medicines.
- Alteration of plant physiology – a possible application in coconut is the introduction of male sterility for making hybrid production easier (Rohde *pers. comm.*).

A review of the use of genetic engineering for food uses in soybean is presented by Kinney (1996). It is considered by some as the only way, food supply can be increased to a level required by the increase in world population (Kasha 1999). Research on the stimulation osmotic adjustment (accumulation of non-toxic compound in plant cells under water stress condition) has been actively conducted in the last 20 years. At the cell level, this accumulation is expected to reduce osmotic pressure and thus maintain water absorption and cell turgor pressure, which might contribute to sustaining physiological processes, such as stomatal opening.

At the plant level, it is expected to lead to increased yield. The physiological and genetic bases of this phenomenon are presented in Zhang *et al*. (1999), along with breeding strategies.

However, the relevance of this mechanism is questioned by Serraj and Sinclair (2002). Their main argument is that, overall, increased crop yields require increased water consumption due to photosynthesis. As a result, such a mechanism is likely to favour water conservation (and thus survival) rather than increased yield. In effect, a review of experimental results shows that favourable effect of osmotic adjustment is mainly observed in extreme drought conditions where yields are very low in all treatments. Such conditions are not compatible with profitable agriculture. These authors suggest that such a mechanism could be useful, only in the case where the maintenance of rood development makes it possible to reach deeper underground water.

Research activities in molecular genetics conducted worldwide related to coconut improvement

Molecular genetics research in coconut has developed significantly since the beginning of the 90's in several fields. The preliminary step was to devise suitable markers and to use them for assessing the genetic diversity in coconut. Once these tools have been developed, they were used primarily for studying the coconut genetic diversity. One of the applications of such studies was the creation of a molecular kit for identifying coconut cultivars. The second potential use was to prepare for marker- assisted selection in coconut. It then became necessary to produce linkage maps.

Devising markers for coconuts

According to their availability in the different laboratories and to convenience, a variety of methods has been used:

- RAPD (Random amplification of polymorphic DNA: Ashburner *et al*. 1997; Duran *et al*. 1997; Wadt *et al*. 1999)
- RFLP (Restriction fragment length polymorphism: Lebrun *et al*. 1999; Lebrun *et al*. 1998)
- AFLP (Amplified fragment-length polymorphism: Perera *et al*. 1998)
- ISTR (Inverse sequence-tagged repeat: Duran *et al*. 1997; Rohde *et al*. 2000)
- Microsatellites (Duran *et al*. 1997; Karp 1999; Perera *et al*. 1999; Rivera *et al*. 1999)

See article on biochemical and molecular methods in Chapter 4 for more details.

Linkage mapping and QTL identification

Two coconut linkage maps have been constructed. The first one was made in the Philippines using hybrid seedlings of a Malayan Yellow Dwarf (MYD) x Laguna Tall (LAGT). A total of 382 markers were placed on 16 linkage groups. Six QTLs for early flowering were identified (Herran *et al*. 2000). The second map was a collective work based on a MYD x Rennell Island Tall planted in Côte d'Ivoire. A total of 227 markers were arranged in 16 linkage groups. Nine QTLs related to fruit number were identified (Lebrun *et al*. 2001). Both of these studies assigned a total length of about 2000cM to the coconut genome. Two other mapping populations; East African Tall (EAT) x Pemba Red Dwarf (PRD) and EAT x RIT in Tanzania are under study in the framework of a European joint research project on oil palm and coconut (INCO LINK2PALM project). More phenotypic observations are being made on these mapping populations in order to identify QTLs. Under INCO LINK2PALM, it is planned to increase the number of markers on the maps. The inclusion of common markers will help the construction of a high-density reference map, which will be useful for further studies.

Devising adapted mapping populations for QTL identification

Although F_1 hybrids have two parents, recombination occurs only between genes from the same parent. Therefore, the usefulness of linkage maps based on this type of hybrids is limited because they exploit only a part of the existing genetic diversity that is related to within-cultivar polymorphism. Moreover, the chances of observing segregation at the same QTL in another cross are less than 50%. Linkage maps based on second generation hybrids do not have these drawbacks. As shown by several studies (see article on biochemical and molecular methods in Chapter 4), a large part of the genetic diversity in *Cocos nucifera* L. occurs between the two major cultivar groups, namely the Pacific group and the Indo-Atlantic group. Thus, a special crossing plan involving second generation hybrids has been devised to identify the QTLs that account for the differences between the two groups (Figure 1). Using such a design will result in more QTLs identified through the choice of genetically distant parental populations. Moreover, it will be easier to use these QTLs in practical breeding because the emphasis will be on the differences between cultivar groups and not on the variation within a cultivar.

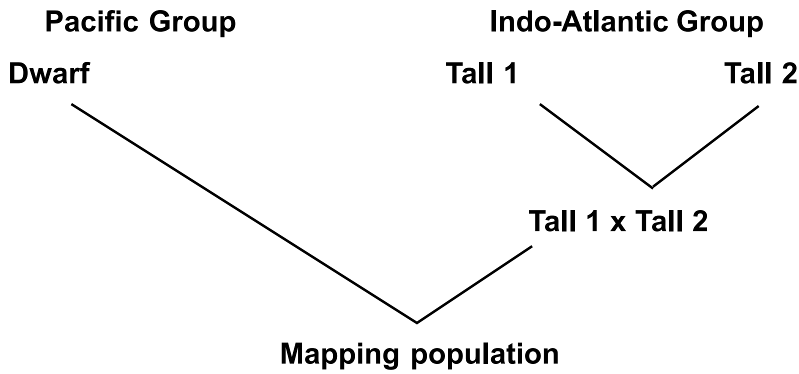

Figure 1. A genetic design adapted to identifying QTLs in coconut.

The use of a well chosen set of Dwarf mother palms as a tester makes it possible to produce a large number of progenies while simplifying the mapping task due to its highly homozygous genetic structure. Such a mapping population is being planted in the Philippines in the framework of the INCO-LINK2PALM project. Another population is available in Côte d'Ivoire.

Results and evidence of the success of MAS in coconut

Usefulness of various markers

As noted earlier, a large number of markers of different types have been designed for coconut. Among them, microsatellites markers are considered as the most useful because they are codominant and highly polymorphic; they give repeatable results, using a non-radioactive PCR technique; and it is not too demanding in terms of DNA quantity or quality. However, other markers, like AFLPs may be useful, particularly for constructing high-density linkage maps. Such maps are useful for two reasons: the closer the mapping of a QTL, the smaller is the probability of a double crossing over between the surrounding markers. Such an event results in selecting plants that have the markers, but not the QTL itself. Although, normally, such an event is relatively rare, it may become a real nuisance in selection programmes that spread over several generations. The second reason is that the region that contain the QTL also contain many other genes, which are not necessary favourable.

Linkage mapping

The available results in linkage mapping demonstrate the feasibility of constructing a map with reasonably good coverage of the coconut genome, thus obtaining 16 linkage groups. Some QTLs for traits related to early development and production have also been identified. The work that is underway through the collaboration of several research teams in the framework of the INCO LINK2PALM project will make it possible to increase the density of markers and also identify more QTL markers in coconut.

In the next few years, another generation of mapping population will be made available for molecular breeding. In these populations, QTLs related to between-cultivar differences rather than on within-cultivar variation is being emphasized. It is expected that such QTLs will be much easier to use in coconut breeding than those located in presently available mapping populations because they correspond to differences between cultivars (and possibly, between molecular groups) rather than differences between individuals of the same cultivar. Their utilization will not be restricted to the exploitation of a single cross.

Prospects of GMOs to date

There has been little progress on developing genetically modified coconuts. The most obvious constraint is the lack of efficient method of plant regeneration method. Other constraints range from the limited amount of research personnel allocated to molecular genetics in coconut to the lack of long-term visibility of the benefit for the planters. For example, modifying the coconut genome to produce high market-value product could increase the planter's revenue, but also make this revenue very dependent on the fluctuations of the market. Such a strategy is easier to justify in an annual crop.

Immediate research needs for using molecular biological techniques for coconut improvement

In the framework of a global programme for coconut, one of the main objectives of molecular breeding research efforts would be to obtain information on the location of important QTLs on the coconut genetic map. As suggested above, such a result can be obtained by exploiting the progenies of wide crosses such as West African Tall x Rennell Island Tall. This objective implies the availability of suitable mapping populations, constructing the corresponding linkage map and performing the necessary observations in the field, in order to correlate phenotypic data and locations on the map. Below are some important elements of research that are required for the successful use of molecular biological techniques in coconut improvement.

Planting and studying suitable mapping populations with molecular markers

Populations corresponding to the genetic structure represented in Figure 1 already exist in Côte d'Ivoire and are being planted in the Philippines. In the case of the Philippines, financing was secured for performing crosses and planting through the INCO LINK2PALM project. Once the population is available, constructing a linkage map involves observing from 300 to 400 markers on 150 to 200 individuals.

Obtaining a large number of good quality observations on mapping population

Molecular markers studies are not a goal by themselves. The benefit from such studies can only be obtained by performing a large number of observations on each of the individuals of the mapping population. This includes traits related to yield and quality of the product, vegetative traits that may be important for adaptation to various environments or to cultivation conditions. A last category corresponds to physiological traits such as photosynthetic efficiency that may be relevant to explaining a genotype's performance.

The resistance to pest and diseases was not included in the above list for the following reasons: assessing resistance is possible only in the presence of the pathogen, which might affect the other traits in an unpredictable way and breeding for resistance requires specific experimental designs. Moreover, for the major diseases affecting coconut, efficient methods for artificially inoculating the palms to create epiphytotic conditions disease screening are lacking and the fate of such resistance trials depends on the rather unpredictable transmission of the disease. Even when the disease is present, the question remains, whether a healthy palm is truly resistant or, simply, was not contaminated.

Reliable small-scale vegetative propagation

Until inoculation methods are set up, small-scale vegetative propagation could help cope with this difficulty. However, in contrast with what was once expected from *in vitro* culture (i.e. production of tens of thousand of plantlets from a single adult palm), the objective has rather been to produce ten to twenty plantlets from about 200 embryos with a 80% success rate. When it becomes feasible to produce significant number of palms through tissue culture, it could help assess resistance to disease, by planting the seedlings produced following an appropriate statistical design. Hence, there is a need for increased research on tissue culture and somatic embryogenesis to be able to produce enough seedlings required for various tests that molecular breeding would demand.

Coconut and genomics

As more and more tools are being developed for locating precisely potential genes of interest, the potential benefits of candidate-gene approach and of physical mapping should be considered. This requires a careful analysis of costs and of potential benefits. Such approaches generally require a very good knowledge of the trait physiology and validating a candidate gene as being the gene of interest requires high resolution linkage analysis in large populations (Pflieger *et al*. 2001) and thus, costs time and money. With regard to disease resistance breeding, the lack of reliable methods for assessing the resistance of individual genotype is a serious limiting factor. Thus, there is a need for serious strategic reflection on genomics in coconut.

Constraints and opportunities

Constraints

Coconut breeding suffers mainly from a severely limited amount of resources, both financial and human. The characteristics of the crop make breeding both slow and costly. It takes at least 14 years for a generation and one hectare for testing each hybrid. Very few coconut-producing countries have the necessary resources for a comprehensive programme and coconut breeding has often been limited to testing a few F_1 hybrids between populations.

Once good hybrids and varieties are selected, the difficulty is to reproduce them and to make seednuts available to farmers. In most producer countries, hybrid seed production has been the main obstacle in extending the hybrids under cultivation. The lack of an efficient vegetative propagation method also makes it difficult to take advantage of breeding progress.

Opportunities

First with the creation of the International Coconut Genetic Resources Network (COGENT), and now with the establishment of a Global Coconut Research for Development Programme (PROCORD), there is an increasing recognition of the coconut as a strategic crop for many tropical countries. Within this framework, coconut-producing countries as well as countries interested to assist them can collaborate, working in a network, for a globally-coordinated coconut breeding programme. Each country can participate in the activities in which it is most interested, within its available resources. Using molecular techniques makes the programme even more attractive. The network may involve laboratories and research teams from developing and developed countries. It can also use other possibilities such as synteny with oil palm.

It must be noted, however, that the use of molecular markers may facilitate breeding but does not replace conventional breeding. The efficiency of marker-assisted breeding still depends on the quality and accuracy of field observations and experimentation.

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Breeding for drought tolerance in coconut: Status and potentials

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Scientific and theoretical basis of breeding for drought tolerance in coconut

Water is among the natural resources required for crop production which is becoming scarce everyday. Efficient management of available water is very important for sustainable crop production. Growing cultivars having efficiency in water use is one of the ways in this direction. It is even more important in the case of coconut, a perennial plantation crop, mainly grown under rainfed and marginal conditions and faces annual summer stress.

Productivity of any crop is dependent on the efficiency (i.e., Water Use Efficiency - WUE) of crop in utilizing the available water for biomass production. Therefore, it will be possible to use WUE as a trait for crop improvement programme (Passioura 1977, 1986). Work on drought tolerance in coconut at the Central Plantation Crops Research Institute (CPCRI), Kasaragod indicated variability for WUE, dry matter production and yield in coconut cultivars (Rajagopal *et al.* 1989; Kasturi Bai *et al.* 1996a). Thus, it should be possible to identify high WUE types with a capacity for high biomass production in order to develop water use efficient coconut types, i.e. with drought tolerance and high yield. Research so far on 75 cross combinations, reciprocal crosses, and their parents, which were screened for drought tolerance and revival capacity at CPCRI indicated that in general, Talls and hybrids with Tall as mother palm had higher drought tolerance compared to Dwarfs and hybrid with Dwarf as mother palm. Heterosis was observed for some of the desirable characters for drought tolerance. Earlier studies (Rajagopal *et al.* 2000a) indicated the possibility of exploiting the heterosis of some of drought tolerant traits in evolving drought tolerant hybrids.

How serious is the problem?

Coconut is mainly grown as a rainfed crop and the productivity is about 50% less in these areas than in irrigated gardens. Coconut faces summer dry spells each year apart from the frequent occurrence of drought years. Being perennial in nature, coconut palm had a long duration from the initiation of inflorescence primordia to nut maturity (about 44 months) with longer pre-fertilization period (about 32 months) than post-fertilization (12 months) period. Hence, the impact of drought occurring at any of the critical stages of the development of inflorescence affects nut yield (Rajagopal *et al.* 1996; Rajagopal *et al.* 2000a) not only during the drought year but also in the following three years making the problem more severe (Naresh Kumar 2002). In worst affected conditions, coconut takes at least four years to recover after going through a stress period. In addition, water deficit at early growth stage could lead to seedling mortality. All these factors result in considerable economic loss to the growers. Planting drought tolerant cultivars with faster recovery potential could alleviate much of this problem. Hence, there is an urgent need for cultivars or hybrids with high drought tolerance capacity and stable yields.

Drought stress affects coconut production in almost all countries where it is grown, since it is mainly a rainfed plantation crop. The environmental stresses affected coconut yield (Coomans 1975; Mathes 1988; Bhaskara Rao *et al*. 1991) in intermediate and dry zones of Sri Lanka (Peiris and Peries 1993; Peiris *et al.* 1995; Peiris and Thattil 1998) and in Zanzibar (Juma and Fordham 1998). Bonneau and Subagio (1999) identified the drought-prone zones in coconut growing areas of Indonesia. All these highlight water deficiency as the major constraint for coconut productivity and the need for coordinated effort to identify and develop drought tolerant cultivars/hybrids.

Environmental factors and coconut

The growth and productivity of coconut palms are influenced by external factors such as rainfall, temperature, sunshine duration and relative humidity. The optimum weather conditions for good growth and nut yield in coconut are well-distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27°C, abundant sunlight ranging from 250 to 350 Wm^{-2} with at least 120 hours per month of sunshine period (Child 1974; Murray 1977). The coconut palm experiences moisture stress when exposed to excess radiation above 265 Wm^{-2}, temperature of 33° C and vapour pressure deficit of 26 m bar (Kasturi Bai *et al.* 1988), aggravated by soil water deficit during the period. The duration of dry spell during initiation of inflorescence primordium, ovary development and button size nut stages, in that order, have greater influence on nut yield than other stages (Rajagopal *et al.* 1996).

Depending on the soil type, the critical level of soil moisture that coconut experiences water stress varies considerably. In sandy loam soil, water deficit of 110 mm is critical at which coconut suffers most due to moisture stress as indicated by the stomatal closure (Rajagopal *et al.* 1989). The photosynthetic rates, dry matter production and its partitioning are influenced by the soil water status (Kasturi Bai 1993: Naresh Kumar *et al*. 2002a). In general, palms suffered more in red sandy loam than in laterite soil as indicated by the stomatal resistance and leaf water potential. The soil types and compaction levels influenced the degree of water stress in seedlings also (Nainanayake and Bandara 1998). Hybrids had higher stomatal resistance resulting in maintenance of higher water potentials during stress in laterite soil than in sandy loam (Voleti *et al*. 1993a). However, the hybrid COD x WCT was found to be most sensitive to water stress in sandy loam soil.

Impact of drought stress on coconut

Coconut palm is influenced both by atmospheric and soil droughts as the palms are mainly cultivated on the coastal sandy, red sandy loam and laterite soils. Under rainfed conditions, a prolonged dry spell extending from 3 to 6 months affects the palm. Based on the weekly water deficiency (WD) and weekly water need (WN), Rao (1985) worked out the 'aridity index' (Ia) for assessing drought. Where Ia= WD / WN x 100. An aridity index of 100% for a prolonged period of 5 to 10 weeks drastically affects productivity of coconut palms. When exposed to such severe moisture stress, coconut palms exhibit adverse effects such as bending and breaking of dry leaves, poor spathe development and almost empty bunches. Based on the aridity index, drought classification was made to asses the extent of damage to coconut palms (Table 1).

Table 1. Relationship between aridity index and symptoms of drought in coconut *(Source: Rao 1985)*

Aridity index (%)	Morphological symptoms	Drought intensity
65	Nil	Slight
65-85	Drooping of lower leaves	Moderate
85-100	Beginning of drying of drooped leaves and button shedding.	Moderately severe
100 for five weeks	Drying of drooped leaves, falling of tender and immature nuts; burning trace on nuts due to the high intensity of radiation.	Severe
100 for > 5 weeks	Palms show the death symptoms, drying of the spindle leaf.	Disastrous

On the other hand, Pomier and de Taffin (1982) calculated 'index to drought tolerance' based on the percentage of dry leaves (n), compared to the number of living ones (N) i.e., (n/N)100. This is based on morphological symptoms alone and is related to nut yield. They reported variation in 'drought tolerance index' among five genotypes with the hybrid PB-121 as the most tolerant and Rennell Tall x West African Tall as the most sensitive to drought. The 'drought tolerance index' was the lowest in the hybrids WCT x PHOT and WCT x GBGD and the highest in WCT x MOD (Ramadasan *et al.* 1991). Repellin *et al.* (1994) also placed PB - 121 under drought tolerant group while WAT was classified as moderately tolerant based on a study of the effect of edaphic drought on the leaf water status, gas exchange and membrane lipids at the nursery stage of five coconut varieties. Kasturi Bai *et al.* (2001) reported the extent of variation in physiological characters among the parents and hybrids at the nursery stage. In Sri Lanka, the drought tolerant Tall x Tall palms were selected based on the mean yield and genotypic adaptation to changes in climate over a 15-year period. Characterization of drought in different coconut growing areas in six states of India falling under different agroclimatic zones revealed that the dry spell length and intensity of stress adversely affect the coconut and consequently nut yield (Naresh Kumar *et al.* 2003). In this study, high adverse effect of length of dry-spell on nut yield was noticed up to four years, with more impact during the fourth year. Apart from this, adverse impact on the current year nut yield was also observed.

Physiological responses to drought stress

Coconut palm responds to drought stress by stomatal regulation and deposition of leaf surface wax (ECW) to maintain leaf water potential. Osmotic adjustment, by accumulation of organic solutes, also plays an important role in the drought tolerance mechanism in coconut (Kasturi Bai and Rajagopal 2000).

Stomatal regulation. Seasonal variations in climatic conditions *viz.*, solar radiation, air temperature and relative humidity influence xylem tension by stomatal regulation, a key factor controlling the water balance in coconut (Milburn and Zimmermann 1977; Rajagopal *et al.* 1986). Development of stress was monitored in coconut during wet and dry seasons by estimating stomatal regulation (Kasturi Bai *et al*. 1988; Juma *et al*. 1997), which varied among cultivars (Voleti *et al.* 1993a). The leaf to air vapour pressure deficit (LAVPD) and leaf to air temperature difference (rT) influenced the stomatal conductance (gs) and water relations during day time and thus predominantly determined the variations in photosynthetic efficiency of coconut in irrigated and rainfed conditions (Rajagopal *et al.* 2000b). Jayasekara *et al.* (1993) identified the drought tolerant genotypes based on the stability in physiological parameters viz., transpiration rate, diffusive resistance and leaf water potential during the stress period.

Leaf water potential. Leaf water potential ($Ø_{leaf}$), an indicator of plant water status, showed a vertical gradation from middle leaf upwards, the magnitude being higher under rainfed condition (Voleti *et al*. 1993b). Seasonal variation among the cultivars for $Ø_{leaf}$ was also noted (Voleti *et al.* 1993a; Shivashankar *et al.* 1991). A rapid screening method was developed based on $Ø_{leaf}$ in excised leaflets (Rajagopal *et al.* 1988) for easy handling of a large number of genotypes. The $Ø_{leaf}$ declined with time to different degrees among the genotypes, indicating the degree of tolerance/susceptibility to stress. These were in conformity with the field-testing conducted for drought tolerance. Passos and da Silva (1991) established the relation between the hydric state of the tree and the diameter of its trunk by dendrometry. From the studies in a group of Dwarf and Tall palms on the root system, stomatal conductance and water potential, it was concluded that the behaviour of palms in drought conditions depends on several factors, *viz.,* water relation components like transpiration, stomatal conductance and leaf water potential as well as agro-meteorological factors like solar radiation, rainfall and humidity, which may interplay to facilitate over all drought tolerance mechanism (Passos and da Silva 1991).

Epicuticular wax (ECW). ECW is one of the important parameters, which influence the energy balance of leaf. In coconut, the ECW on leaves did not differ significantly among cultivars and hybrids under favourable conditions. However, almost three to four fold increases in ECW was noticed during dry season in some of the coconut hybrids *viz.*, WCT x GBGD, WCT X COD, LCT x COD and LCT x GBGD (Voleti and Rajagopal 1991; Kurup *et al.* 1993). The physiological age of palms and of leaves influenced the formation of wax on leaf surface. Leaves of coconut seedlings have almost 50% less ECW than those of adult palms even at the same degree of stress.

Osmotic adjustment. Coconut palms accumulate organic solutes such as sugars and amino acid during stress period. Accumulation of these solutes was more in the tolerant types than the susceptible types during severe stress condition (Kasturi Bai and Rajagopal 2000). This implies that osmotic adjustment plays an important role in the drought tolerance mechanism in coconut.

Root-shoot signals. Roots in drying soil are known to over produce abscisic acid (ABA) thus providing signals to shoot for closure of stomata for water regulation in plant (Zhang and Davies 1989). Root-shoot relationship was also reported to be an effective indicator of soil compaction and water stress for coconut seedlings (Nainanayake *et al.*

2000). High ABA/cytokinin ratio in leaf has positive influence on water use efficiency (WUE), whereas a high ABA/ cytokinin ratio in root has a negative influence on WUE in coconut seedlings (Kasturi Bai 2003).

Biochemical responses to drought stress

The biochemical responses of coconut palm to drought stress include regulation or synthesis of scavenging enzymes to maintain cell membrane integrity thus enabling cells to tolerate stress.

Effect of water deficits on enzyme activity. Concomitant with the decrease in the leaf water status during drought stress, the activities of stress sensitive enzymes differ depending upon the nature and function of the enzyme in question. Drought stress caused an increase in the activities of some of the stress sensitive enzymes viz., peroxidase (PO), polyphenol oxidase (PPO), superoxide dismutase (SOD), acid phosphatase (APh) and L-aspartate: 2-oxoglutarate amino transferase (AAT) in adult WCT palms, while activities of Malic dehydrogenase (MDH) and nitrate reductase (NR) were decreased (Shivashankar *et al.* 1991; Kasturi Bai *et al*. 1996 b, Kasturi Bai *et al*. 2003). Drought tolerant varieties are endowed with a biochemical mechanism in adapting the adverse effects of drought through appropriate regulation of enzyme activities. Many enzymes exist in multiple molecular forms called isozymes and changes in the activity or appearance of isozymes represent the relative tolerance of coconut cultivars to water stress (Shivashankar 1988). Increased intensity of APh isozyme II shows the susceptibility of the genotype to water deficits since APh is a hydrolytic enzyme (Shivashankar and Nagaraja 1996). Two additional fast moving bands of PPO were located in the drought susceptible varieties under stress, while the drought tolerant cultivars showed no change (Shivashankar 1988). The variability in the isozyme patterns of enzymes like esterase, peroxidase, phosphoglucoisomerase, alcohol dehydrogenase, glutamate oxaloacetate transaminase and acid phosphatase were also reported in coconut germplasm (Fernando and Gajanayake 1997).

Membrane stability in relation to drought stress. At the cellular level, the impact of stress is generally seen on the integrity of membranes and extent of solute leakage, which is regulated by the cell membrane stability. Normal cell functions are affected due to changes in peroxidation of cell wall lipids (LP) during stress resulting in increased cell permeability and solute leakage. In coconut, lipid peroxidation was high in drought susceptible cultivars as compared to tolerant ones (Chempakam *et al.* 1993). Drought tolerance is thus characterized by higher activities of the protective enzymes like SOD, catalase and peroxidase and consequently coupled with lower levels of lipid peroxidation and higher membrane integrity. Coconut seedlings of the tolerant group maintained lower water loss and lipid peroxidation than the susceptible group and a negative correlation between leaf water potential and lipid peroxidation was observed (Kasturi Bai *et al*. 2001). Repellin *et al.* (1997) observed marked reduction in total leaf lipid and chloroplastic major lipid (monogalactosyl diacylglycerol) contents in drought susceptible cultivars.

Role of K^+ and Cl^- nutrition in relation to drought tolerance in coconut

The role of K^+ and Cl^- nutrition in relation to drought tolerance in coconut has been explained on the basis of stomatal regulation (Braconnier and D'Auzac 1990; Braconnier and Bonneau 1998). Unlike in most of the crops where malate serves as a balancing ion for K^+, in coconut the absence of chloroplasts in the guard cells deprives the availability of malate (Braconnier and D 'Auzac 1985). Increase in drought tolerance of palms under dry conditions with the addition of KCl was reported in Ivory Coast (Ollagnier *et al*. 1983; Rajagopal and Naresh Kumar 2001). Chlorine is important in coconut nutrition and for resistance to water stress; the critical level of Cl was identified as 0.7% in 14th leaf (Bonneau *et al.* 1993 and 1997). Potassium nutrition also plays an important role in drought tolerance in coconut (Quencez and de Taffin 1981; Bopaiah *et al. 1996).*

Screening for drought tolerance

The cell size and number, sub-stomatal cavity size, stomatal frequency, epicuticular wax content and thickness, leaf thickness, stomatal resistance water potential components, cell membrane stability are the essential anatomical and physiological traits for assessing moisture stress in plants (Rajagopal *et al*. 1991; Repellin *et al.* 1994; Naresh Kumar *et al.* 2000). Based on these, coconut germplasm collections comprising of Talls, Dwarfs and hybrids were screened under field conditions for drought tolerance (Rajagopal *et al.* 1990).

Genetic variation in leaflet anatomy in relation to drought tolerance

The anatomical basis for physiological efficiency for drought tolerance in coconut was delineated (Naresh Kumar *et al.* 2000). The study revealed that the leaf anatomical features which favour high photosynthetic rates are favourable for high transpiration rates as well. Thicker leaflets and thick cuticle are some of the xeromorphic characters observed in WCT and FMS. Correlations between anatomical features and physiological parameters also indicated that thick cuticle lowers the cuticular transpiration. The WCT and FMS, which are tolerant to water stress, had thick leaflets, thick cuticle on both surfaces, larger parenchyma, hypodermal and water cells compared to less tolerant ones (COD x WCT, GBGD and MYD). Drought tolerant types had also more scalariform thickening on xylem trachieds in vascular bundles and large sub-stomatal cavities. These traits are lesser in size in moderately tolerant cultivar like PHOT and WCT x COD. The values for these traits were least in susceptible types like COD x WCT, GBGD and MYD. However, the differences for these traits between moderately tolerant and susceptible cultivars were not great. Certain parameters like epidermal cell size (upper and lower) and guard cell size are related to the drought tolerance character of a cultivar. It is possible that the cumulative effects of all these traits contribute to drought tolerance (Naresh Kumar *et al.* 2000).

Ranking of cultivars for drought stress tolerance

All the aforesaid parameters showed clear differences between the groups and among the cultivars within the group. A significant negative correlation between stomatal resistance and transpiration rate was found in Talls, Dwarfs and hybrids. Ranking for drought tolerance was done based on all stress sensitive parameters (*viz.*, stomatal regulation, leaf water potential, lipid peroxidation, ECW content, polyphenol oxidase, super oxide dismutase, catalase and peroxidase) using parametric relationships (Rajagopal *et al.* 1990; Chempakam *et al*. 1993). All Dwarfs performed badly ranking ranks between 11 and 20, whereas all hybrids (except COD x WCT) and all Talls (except the SS Apricot, Andaman Ordinary and Laccadive Micro) were within rank 10. Based on anatomical features such as thicker leaflets, thick cuticle on both surfaces, larger palisade and spongy parenchyma cells, larger hypodermal cells, water cells and sub-stomatal cavity, genotypes like WCT, FMS and PHOT and WCT x COD hybrid were identified as relatively tolerant to drought stress (Naresh Kumar *et al.* 2000).

Thus, coconut cultivars with different levels of drought tolerance could be identified based on the desirable traits, which reflect on the overall water relations of palms. Presence or absence of desirable traits imparts higher degree of drought tolerance (e.g. WCT x WCT; FMST; LCT; WCT x COD, LCT x GBGD and LCT x COD) or drought susceptibility (e.g. MYD) (Rajagopal *et al.* 2000a).

Two cultivars - San Ramon and Ambakelle Special - were identified as drought tolerant in Sri Lanka (Wikremaratne 1987 and Fernando 1987). In Cote d'Ivoire, PB–121 was identified as tolerant while WAT was classified as moderately tolerant and Rennell Tall x West African Tall as the most sensitive to drought based on drought tolerance index and effect of edaphic drought on the leaf water status, gas exchange and membrane lipids (Pomier and de Taffin 1982; de Nuce de Lamothe and Benard 1985; Repellin *et al.* 1994).

Genetic variability for photosynthetic efficiency and water use efficiency of coconut under drought conditions

The photosynthetic rates (*Pn*) were reduced by water stress mainly due to increase in stomatal or mesophyll resistance, with higher reduction noticed in susceptible types than in tolerant types (Kasturi Bai *et al.* 1998). Drought tolerant hybrids such as WCT x COD, LCT x GBGD and LCT x COD exhibited higher increase in *Pn/gs* ratio as well as higher WUE than that of susceptible types during stress period.

The potential of palms for higher dry matter (DM) production is reflected on WUE. WUE can be determined based on dry matter accumulation (g DM mm water^{-1} used) as well as by gas exchange measurements (µmol CO_2 mmol^{-1} H_2O). Significant difference in WUE has been observed between the cultivars and hybrids. The hybrids WCT x COD, LCT x GBGD and LCT x COD, and cultivar WCT had higher WUE than the other cultivars and hybrids. Under mild stress conditions, the WUE improved in coconut juvenile palms (Rajagopal *et al.* 2000b).

Recently, efforts are on to find high WUE types in coconut germplasm using carbon and oxygen isotope discrimination method at CPCRI, India; Coconut Research Institute (CRI), Sri Lanka; and Essex University, United Kingdom.

Field trials: Nut yield in relation to intensity and length of drought stress

The intricate relationship between dry spell and stages of nut development right from inflorescence initiation to the nut maturity as well as annual nut yield in different agroclimatic zones have been well described in literature (Rajagopal *et al.* 1996; Rajagopal *et al.* 2000a). Physiological traits responsible for drought tolerance correlated with yield performance under stress conditions and some of the cultivars identified as drought tolerant also proved to be good yielders (Bhaskara Rao *et al.* 1991; Rajagopal *et al.* 1992). There were genotypic variations for drought index (Pomier and de Taffin 1982) in coconut. Naresh Kumar *et al.* (2003) worked out the influence of soil moisture conservation practices on source-sink relationship in coconut.

Drought tolerance mechanism in coconut

All the above-mentioned research results helped in deciphering the mechanism of drought tolerance and stability in yield of coconut under water stress conditions (see Fig. 1). To sum up, drought tolerance in coconut is the cumulative effect of several inductive morphological, anatomical, physiological and biochemical mechanisms (Rajagopal and Kasturi Bai 2002, Naresh Kumar *et al*. 2000). The genotypes possessing the above traits of drought tolerance can be used in breeding programmes. The genetics of these important traits are being looked into for developing future coconut improvement strategies.

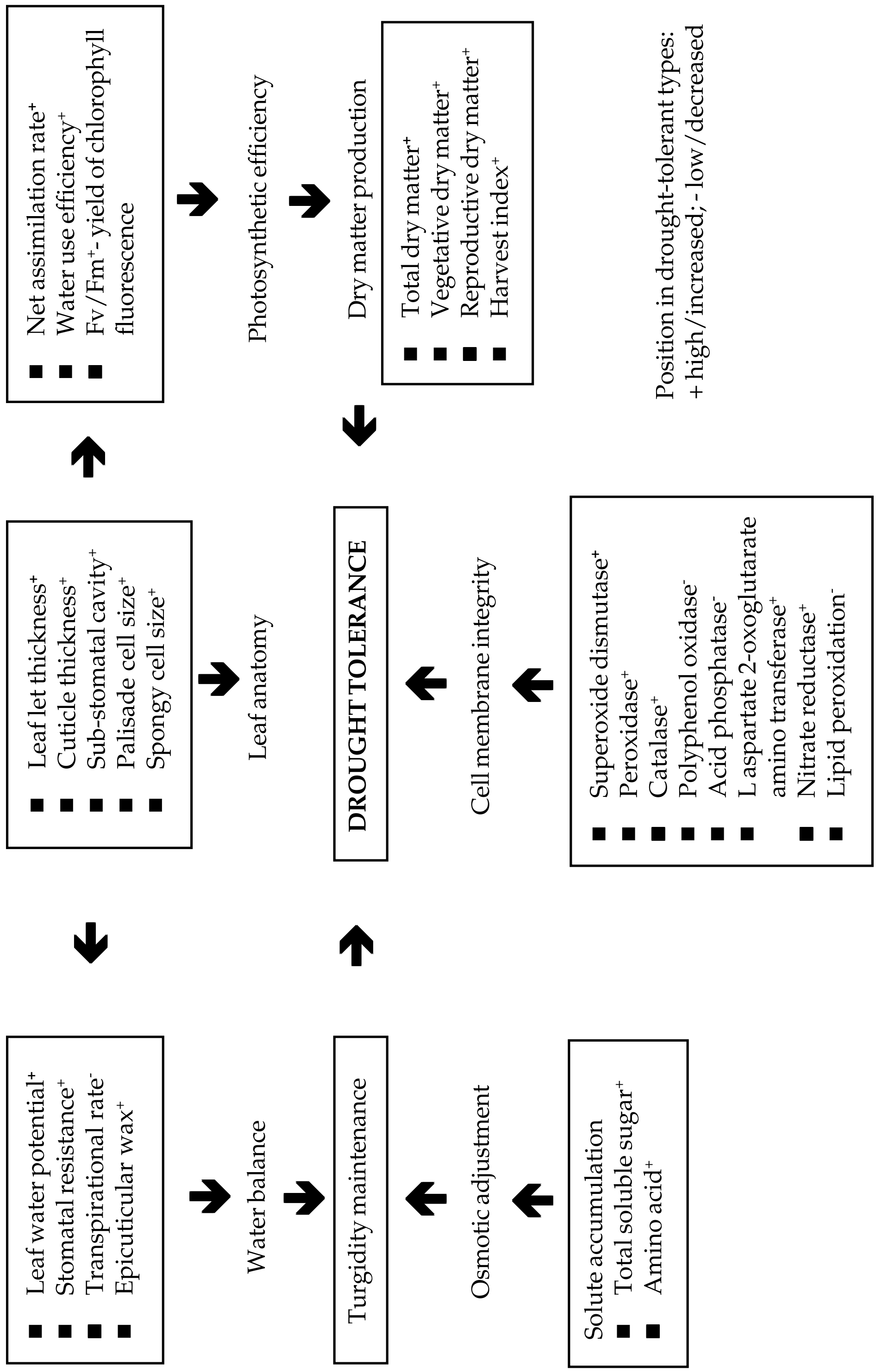
Genetics of drought tolerance related to physiological and biochemical traits

To understand the genetics of drought responsive physiological traits in coconut (Rajagopal *et al.* 2000a), cultivars with desirable characters were selected and crossed in a 2 x 4 line x tester mating design to study their combining ability and gene action. Physiological parameters like, leaf water potential, transpiration rate, net photosynthetic rate (*Pn*) and lipid peroxidation were recorded in seedlings under non-stress, water stress and recovery conditions. Analysis of variance for combining ability revealed significant differences among parents and hybrids for all characters except transpiration rate on recovery and leaf water potential under stress. Seedling transpiration rate showed higher specific combining ability (SCA) effects than general combining ability (GCA) effects due to predominance of non-additive gene action indicating heterosis for this character. Leaf water potential showed a similar trend. The *Pn* under stress was additive with good combining ability, while the *Pn* during non-stress and recovery were governed by non-additive gene action that could be exploited for heterosis. In case of lipid peroxidation, gene action was unpredictable in non-stress with additive gene action being nil with low dominance. These indicate that the nature of gene actions governing drought sensitive traits can be exploited by selecting proper breeding strategies for drought tolerance.

Methodology for screening drought tolerance in coconut

Drought tolerant coconut palm can be selected at seedling stage in nursery and at maturity stage. Apart from these, one can use *in vitro* screening technique as well. The screening of coconut germplasm can be done using morphological, anatomical, physiological and biochemical traits (see Fig. 2). Molecular marker-assisted selection could also be used once developed. It is essential to note that one has to develop the threshold levels for development of stress in a given climatic and soil conditions.

Figure 1. Mechanism of drought tolerance in coconut



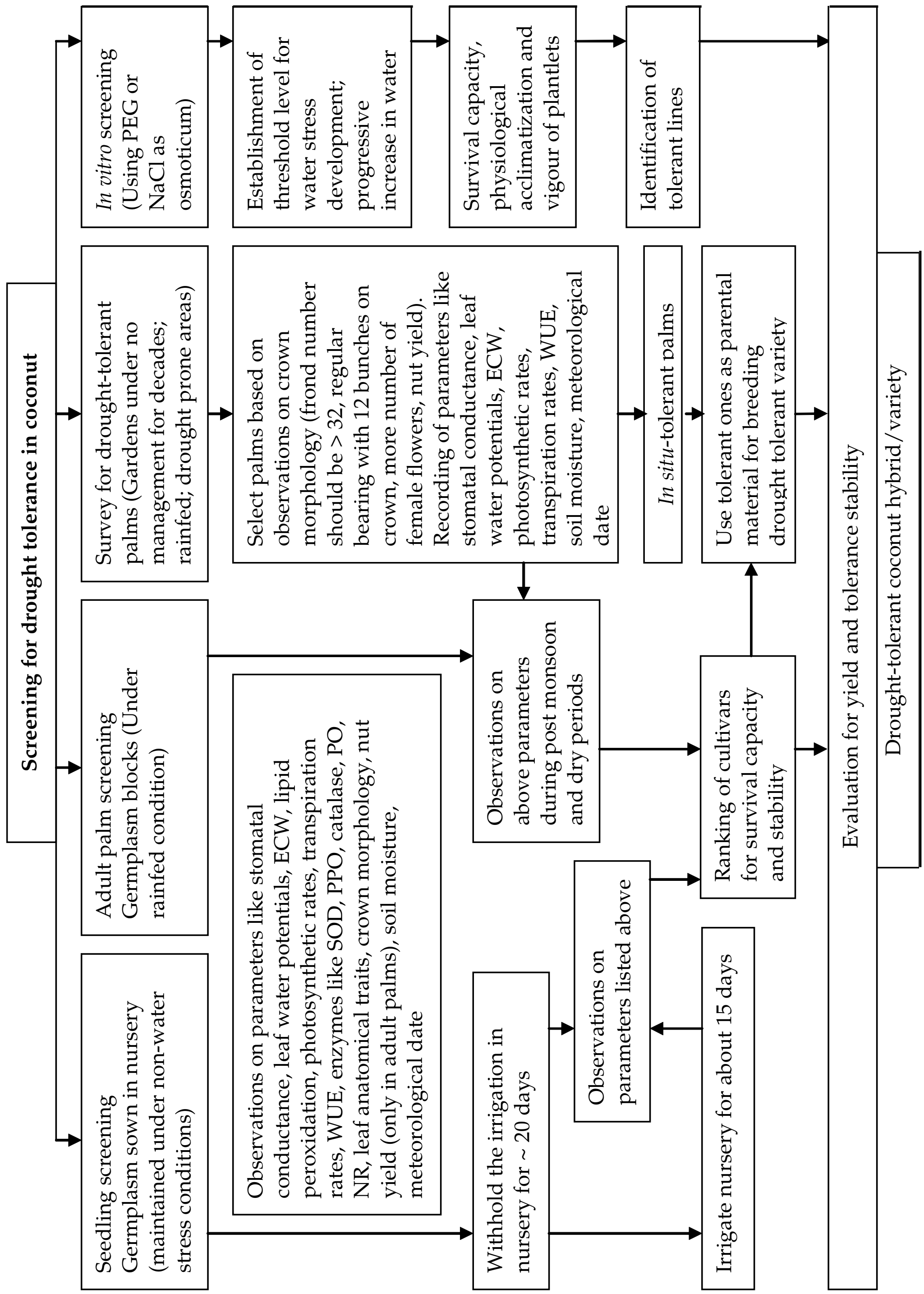


Figure 2. Schematic diagram for screening drought tolerant coconut germplasm

Identification and characterization of *in situ* tolerant palms

The plants that can withstand the natural occurrence of drought and other stresses and still produce good yields are of premium value, as they are likely to possess desirable genes. Surveys in hotspot areas were conducted to identify the palms yielding very high compared to others in their vicinity. Palms at different agroclimatic regions were identified in farmers' plots with desirable canopy shape and leaf number with good yields. The physiological WUE of these palms was also found to be high (Naresh Kumar *et al*. 2002b). This type of *in situ* tolerant plants with desirable traits should be used in breeding programmes, to reduce the time gap in breeding for drought tolerant cultivars in coconut (Naresh Kumar *et al*. 2002b).

Molecular markers for drought tolerance traits

In coconut, the development of molecular markers for drought tolerance is in its infancy. The work on stress responsive proteins is being carried out at CPCRI (Naresh Kumar 2003). Efforts are on to link the drought tolerance to molecular diversity to find putative molecular markers, which can be useful for marker-assisted selection (MAS). Although the lack of a viable regeneration technique is a bottleneck for genetic engineering of coconut palm, the molecular markers should be identified for use in large-scale rapid screening of germplasm. This will not only increase the efficiency for selection of parental material but will also reduce the gestation period for breeding improved varieties with drought tolerance (Batugal 1999). The RFLP analysis indicated that Tall and Dwarf ecotypes from Pacific and Far East Asia were different from those from India, Sri Lanka and West Africa (Lebrun *et al*. 1998, 1999). An *in vitro* screening technique was developed using NaCl as the osmoticum at different concentrations in coconut embryo culture medium (Karunaratne *et al.* 1991). It is possible to link the *in vitro* and nursery screening techniques to molecular techniques for development of molecular markers. Once the markers are established, they will be of prime importance to identify the parental material in breeding for drought tolerance. At the same time, it is essential that the stability of drought tolerance through pheno-phases should also be established.

Thus, the development of molecular markers and application of biotechnological tools for the improvement of drought tolerant coconut varieties need more emphasis and concerted efforts. The future challenge is in overcoming the bottlenecks in the use of genetic engineering for the development of drought tolerant coconut variety.

Constraints and opportunities

Drought is a major constraint for coconut productivity in the entire coconut growing area at global level. The realization of the impact of drought on coconut yield increased attention towards this problem. A methodical research approach led to understanding the drought tolerance mechanism in coconut. So far, conventional breeding strategies were applied for the development of drought tolerant varieties/hybrids. However, this takes a lot of time and so is testing for yield stability under stressful conditions. The lack of regeneration techniques handicapped the genetic engineering approach to impart drought tolerance in high yielding cultivars. Hence, it is very important that a globally-coordinated breeding programme for drought tolerance be set in place, as studies indicated that hybrids with Talls as parents can perform better under water stress conditions (Pomier and de Taffin 1982; Rajagopal *et al.* 1990). It is essential to conserve the natural desirable gene pools present in farmers' fields before they become extinct. These materials are highly valuable for crop improvement programme. Molecular markers need to be developed for rapid screening of coconut germplasm for drought tolerance at global level. Further, it is important to characterize the nature and intensity of drought in different coconut growing areas in order to develop suitable drought management strategies.

Conclusion

The results obtained so far indicate that variation exists among the Talls, Dwarfs and hybrids for drought tolerant traits. Generally, Talls and hybrids with Tall as mother palm have higher drought tolerance compared to Dwarfs and hybrids with Dwarf as mother palm. The heterosis for desirable traits can be exploited for breeding drought tolerant varieties. Further, *in situ* tolerant palms should be identified and used in breeding programme. These experiments can be extrapolated to other germplasm sources, which were not studied so far, and for making promising cross combinations. Since this requires a comprehensive study, a global research network on this topic will facilitate the development of varieties/hybrids with high drought tolerance and stable yield.

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Performance of coconut hybrids in some countries of Asia, Africa and Latin America

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Introduction

Coconut (*Cocos nucifera* L.) varieties grown worldwide are popularly classified as Tall, Dwarf or Hybrid. The Talls (T) and the Dwarfs (D) are mostly selected races of economic importance among the local farmers. Most of them evolved from continuing natural or mass selection. The hybrids are mostly produced from intercrossing these selected races or traditional varieties (i.e., D x T, T x D, T x T) to develop the desired ideotypes, which for most breeders meant varieties with broad adaptability, pests and disease resistance, and high yield.

Promising hybrids

A few capable national coconut breeding programmes in coconut growing countries, either on their own or through foreign-assisted projects, have been in the forefront of collecting, conserving, evaluating and breeding coconut germplasm since the early 1980s. Each of these country programmes has produced their own set of recommended or promising hybrids. A survey of the performance of some of these hybrids was conducted by the International Coconut Genetic Resources Network (COGENT) (Batugal 2004), and the results of this survey are summarized and analyzed below.

China

The Wenchang Coconut Research Institute's sole recommended hybrid is a cross between Malayan Yellow Dwarf (MYD) and the local Hainan Tall (HAT) variety. This MYD x HAT hybrid (WY78F1) exhibited early flowering (3-4 years) and 3-4 fold increase in terms of harvested nuts (80/palm/year) and copra (4 t/ha/year), compared to the Tall parent.

The Philippines

The Philippine Coconut Authority (PCA) recommended nine hybrids derived from single crosses involving the local cultivars, Catigan Green Dwarf (CAT), Tagnanan Tall (TAG), Baybay Tall (BAY), Laguna Tall (LAG), Bago-Oshiro Tall (BAO), and the introduced varieties, Malaysian Red Dwarf (MRD) and Polynesian Tall (PYT). Most of these recommended hybrids started flowering on the 3rd to 4th year. The average number of nuts per palm ranged from 117 to 155 and copra yield per hectare, from 4-6 tonnes. The local tall BAY was comparatively good producing 114 nuts/palm with a copra yield of 5t/ha. Among the nine hybrids, MRD x TAG (PCA 15-2) and MRD x BAY (PCA15-3) were outstanding giving the highest number of nuts (144-155/palm) and copra yield (6t/ha).

Thailand

The Chumphon Horticulture Research Centre (CHRC) of the Horticulture Research Institute of Thailand recommends three high-yielding hybrids: Sawi Hybrid No.1 (an introduced hybrid known as PB 121 or MAWA), and the locally developed hybrids Chumphon Hybrid No.60 (Maphrao Yai or Thai Tall x West African Tall) and Chumphon Hybrid No. 2 (MYD x Thai Tall). A trial comparing the locally developed hybrids with the local Thai Tall (THT) in 1975 showed that THT yielded the least. The recommended hybrids exhibited nut and copra yields ranging from 80-126/palm and 3.4 4.2t/ha, respectively.

Vietnam

The Oil Plant Institute (OPI) of Vietnam recommends seven introduced high-yielding hybrids in the country which have significantly outyielded the local Tall (Ta). The introduced hybrids were PB111, PB121, PB 132, PB 141, JVA 1, JVA2 and CRIC 65 with nut production ranging 48-69/ palm in 1996. The local variety Ta yielded 31-35 nuts on the same year. OPI is currently testing six local hybrids in Dong Go Experimental Center (Eo x Ta; Tam Quan x Ta; Tam Quan x BAOT); and in Binh Thanh Experimental Station (MYD x Renell Island Tall; MYD x Palu Tall; and MYD x Ta).

Bangladesh

The Agricultural Research Institute (BARI) has developed two high-yielding coconut varieties: BARI Narikel –1 and BARI Narikel-2. These varieties are broadly adapted and capable of producing 65-70 nuts/palm throughout Bangladesh. In addition, BARI is recommending two introduced varieties to the country’s coconut growing communities, namely: Sri Lanka Tall (SLT) and Malaysian Yellow Dwarf (MYD).

India

The Central Plantation Crops Research Institute (CPCRI) has released the largest number (12) of single-cross hybrids among the surveyed countries, involving Chowgat Orange Dwarf (COD), West Coast Tall (WCT), Laccadive Ordinary (LCT), Gangabondam (GBGD), MYD, SS Apricot by KAU (SSAT) and East Coast Tall (ECT). All the hybrids performed better than the traditional cultivar WCT. The recommended hybrids have reported average nut yields of 98– 156/palm while the WCT has only 80 nuts/palm of recorded yield. COD x WCT (Chandra Sankara), WCT x SSAT (Kera Sowbagya) and WCT x MYD (Kera Sree) produced the highest copra yields (i.e., more than 4 t /ha/year).

Sri Lanka

The Coconut Research Institute (CRI-SL) has developed two hybrids, [(Sri Lanka Green Dwarf (SLGD) x Sri Lanka Tall (SLT)] and SLT x SR, and a first generation inbred (SLT x SLT) for its national replanting programme. Their yields ranged from 80-125 nuts/palm and 3.6 – 4.0t copra/ha. Hybrids' nut yields are double that of the usual yield of the local cultivar, Sri Lanka Tall, but their copra content/yields are similar.

Vanuatu

The Vanuatu Research and Training Centre have produced hybrids involving the local cultivars Vanuatu Tall (VTT) and Vanuatu Red Dwarf (VRD), and the introduced varieties Renell Island Tall (RIT) and Brazilian Green Dwarf (BGD). The Malaysian Red Dwarf (MRD) was also used as a mother palm for crossing with RIT but the resulting hybrids only performed slightly better (in terms of copra yield) compared to the local VTT and were very susceptible to coconut foliar decay (CFD). The BGD crossed with either RIT or VTT produced the best copra yields of 4.4-5.2 t/ha but they were also found to be very susceptible to CFD. The VRD x VTT hybrids had lower copra yields (3.3-3.7t/ha) but were found to be more tolerant against CFD. Both the traditional and improved VTT types had the lowest reported copra yields of 2.6-2.8 t/ha, but comparable with the hybrid MRD x RIT.

Côte d'Ivoire

The CNRA Marc Delorme Research Station has initially identified seven outstanding hybrids: PB 213 (WAT x RIT), PB 214 (WAT x VTT), PB121 (MYD x WAT), PB 132 (MRD x TAT or Tahitian Tall), PB123 (MYD x RIT) and PB111 (CRD or Cameroon Red Dwarf x WAT).These hybrids flower very early (40-57 months after field planting) under Côte d'Ivoire conditions. Despite early flowering, they produced from 100 to 132 nuts/palm/year, which is 34% to 138% higher than the population control West African Tall (WAT). Further, their copra yields ranged from 3.15-4.8t/ha or 86-135% more compared with WAT.

Ghana

All coconut cultivars in Ghana are considered to be at risk from the Cape St. Paul Wilt disease (CSPWD), a lethal yellowing type of disease. Hence, the coconut breeding programme in the country is geared towards developing hybrids resistant or highly tolerant to CSPWD. There are six cultivars and 21 hybrids being tested in four locations: Cape Three Points, Discove, Agona Junction and Akwidae. These varietal resistance trials are still under observation although some of the test materials were already totally infected by the CSPWD.

Tanzania
The Mikocheni Agricultural Research Institute (MARI) is currently testing six hybrids with the local East African Tall (EAT) as sole pollinator. Mother palms included the Malayan Green Dwarf (MGD), CRD, Pemba Red Dwarf (PRD), MYD, MRD and improved EAT populations. In addition to determining their yield performance, the F_1 progenies are also being evaluated for their resistance to lethal disease and tolerance to drought stress.

Mexico
Coconut research at the Instituto Nacional de Investigacion Agropecuaria Y Forestal is focused on developing hybrids resistant to lethal yellowing disease (LYD). Initial hybrids were mainly derived from crosses between MYD and improved Pacific Tall populations. Intra population crosses of selected Pacific Tall were also done and these are currently being tested.

COGENT, through its CFC-funded multilocation trials, is in the process of determining the suitability of selected hybrids across its member countries (see Batugal *et al.*, this chapter). The inclusion of all promising hybrids, however, is constraint by financial and material resources limiting the number of hybrid entries and location trials.

Conditions favouring coconut hybrid performance and use

Agroclimatic
In a comprehensive hybrid performance assessment study (Rethinam *et. al* 2004) initiated in 1998 in 10 countries, most of the participating countries reported that, with few exceptions, hybrids generally came into early bearing and exhibited better productivity in the wet zones than in intermediate and dry zones. The result of the study suggested that to maximize the potential of most hybrids, they should be planted under favourable soil and moisture conditions.

Farmers' preferences

As part of the Asian and Pacific Coconut Community (APCC)/COGENT study, farmer respondents in the surveyed countries were asked to indicate their varietal preference and their reasons for their selection. Of the total 381 responses, 55.6% were in favour of hybrids and 28% preferred planting the local and/or selected Talls (Table 1). However, individual countries showed diverse rates of preference for hybrids. In Samoa, all the farmers covered in the survey stated they would grow hybrids, given a second chance. In Thailand, 70% of the farmers remained satisfied with the hybrids and the rest preferred to plant Tall variety. In Indonesia, where hybrids have already spread to a large extent, only 5.56% wanted to plant the same coconut hybrids while 99.44% opted for selected local Talls and locally produced hybrids for planting the next time. High yield, early bearing and good nut size were cited as the main reasons for satisfaction with the hybrids. And the major reasons made known by the farmers for their dissatisfaction with hybrids are their being vulnerable to moisture stress, high input requirement and susceptibility to pests and diseases.

Table 1. Farmer's preferences of cultivars, given a second chance (number of responses)
Source: (P Rethinam, P Batugal and F Rognon, 2004)

Zone	Tall	Local/ Selected Hybrids	Dwarf	Total
Wet	31	91	43	165
Intermediate	59	75	8	142
Dry	18	46	10	74
TOTAL	**108**	**212**	**61**	**381**

Narrowing the technology gap

Although hybrids are generally known to perform better than the traditional varieties, they are currently being grown in limited areas, less than 0.1 (or even nil) to 14% of cultivated coconut farms in various countries (Table 2). The poor adoptions of hybrids are commonly attributed to inadequate information dissemination on the availability of improved hybrids/varieties, lack of adequate supply and affordability of planting materials, and inadequate management and cultural practices. These factors resulted to failure in narrowing down the productivity gap between the farmers' fields and research stations. Comparing the national yield average in farmers' fields and those of research centers in 15 coconut growing countries, the estimated technology gap in terms of either nuts or copra yield ranged from 33 to 84% (Table 2). To maximize the potentials of using hybrids to increase the income of resource-poor farmers and the total national coconut productivity, an effective campaign to disseminate suitable planting materials should address the reasons cited earlier for the poor adoptions of hybrids.

Table 2. Coconut productivity in farmers' field and research stations, and area planted to hybrids
Source: (P Batugal and J Oliver, 2003)

Country	Annual yield				Technology gap [100-(A/B x100)]	Area grown to hybrids (% of production area)
	(A) Farmers' Fields/National Average		(B) Research Station/Hybrids			
	Nuts	Copra	Nuts	Copra		
	(t ha^{-1})		(t ha^{-1})			
South Asia						
Bangladesh	21/palm		69/palm		70	nil
India	6892/ha		23 700/ha		71	14
Sri Lanka	42/palm		63/palm		33	11
Southeast/East Asia						
Indonesia		1.1		3.5	69	5
Malaysia	10 000/ha		23 000/ha		57	n.d.
Philippines		0.78		4-6	84	n.d.
Thailand		1.2-1.5		3.0	55	10
Vietnam	38-40/palm		55-80/palm		42	<0.1
China		1.27		3.6	65	1.5
South Pacific						
Fiji		0.3-0.5		2.0	80	<5
PNG		0.66		2.8-3.6	80	n.d.
Africa						
Ghana	20/palm			n.d.		3
Tanzania	40/palm		80/palm		50	n.d.
LAC						
Jamaica		0.8		3.7	78	n.d.
Mexico		0.65		4.0	84	1

Conclusion

The country reports on recommended hybrids (Batugal 2004) and the APCC surveys on the performance of high-yielding hybrids and farmers' varietal preferences indicated that there is no universal hybrid and that, generally, hybrids perform better than traditional varieties under good rainfall and soil conditions. Based on these analyses, national breeding programmes should be designed to develop and provide either varieties or hybrids that suit specific agroecological conditions and small-scale farmers' needs. In the end, each national coconut breeding programme should be able to propose to farmers a set of well-evaluated varieties including Dwarfs, Talls, and Hybrids.

COGENT is proposing a global breeding programme to address the collective needs of COGENT member countries instead of merely those of individual countries and the adoption of participatory plant breeding approach to incorporate farmers' varietal preference. The programme aims to significantly increase the choice of hybrid cultivars among coconut growing countries, by maximizing the use of available genetic resources for breeding purposes, facilitating the development of efficient breeding tools and varietal selection, and improving the quality of the planting materials for distribution to users or farmers.

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Performance evaluation of coconut varieties and farmers' varietal preferences

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Introduction

Coconut, (*Cocos nucifera* L.) has two forms, the Talls and Dwarfs. Predominantly, in all coconut growing countries, Tall varieties are commercially grown for copra and oil. Dwarfs are primarily grown in a limited area for ornamental purpose as well as for its sweet tendernut water for drinking. Talls are highly cross pollinated and hence, the variations in nuts are spectacular. Dwarfs are mostly self pollinated. Studies on varietal improvement using the existing germplasm were taken up in many countries over a period of more than seven decades. This has resulted in the identification of many high yielding varieties and hybrids of different Tall and Dwarf combinations. Inter and intra-varietal crosses were made to develop progenies with combined desirable characteristics of parents and over-dominant traits particularly on yield performance.

In India, the first report on hybrid vigour in progenies resulting from the crosses between Tall and Dwarf varieties was available in 1932. In Sri Lanka, the results of exploratory crosses became available in 1948. In both these countries, organized production and distribution of hybrid planting material began in the early fifties. Similar programmes were taken up in the seventies by other countries especially Indonesia, Côte d'Ivoire, Malaysia, Philippines and Vanuatu.

Although many high yielding varieties and hybrids were developed and commercial seed production programmes were started, there were always some reservations by small holders of coconut in using them as planting materials. In order to assess the extent of adoption of these varieties and hybrids by farmers, identify the constraints experienced by the farmers in adopting them under field conditions and further assess the yield performance of these hybrids and varieties, three studies were conducted during the year 1980, 1988 and 1998 in different coconut growing countries.

High-yielding varieties and hybrids

Among the traditionally cultivated Tall (T) varieties, there are genetically superior palms possessing intrinsic traits for high yield. Such elite palms have been identified in some countries and used for seedling production and for intravarietal crosses. Similarly, these palms have also been used either as pollen parents or female parents in intervarietal crosses with Dwarf (D) varieties. The resulting progenies were therefore, either T x D hybrids or D x T hybrids depending on the pistillate parent involved.

Sri Lanka was the first country to produce T x T hybrids from isolated seed gardens planted with progenies of selected T x T crosses. Natural cross pollination was permitted to take place between the planted progenies without resorting to emasculation. The T x T hybrid so produced is known by the name CRIC 60 which is superior to the local Tall cultivars. The hybrid palms commence flowering at 5-8 years from planting and yield about 100 nuts per palm per annum. The copra content per nut is about 200g. They are generally hardy palms and tolerant to drought, pests and diseases and are recommended for planting in all districts in Sri Lanka. The hybrid CRIC 65 has been released to the farmers in the sixties. This hybrid flowers in 3-4 years from planting, yields about 120 nuts per palm per year with a copra content of 200-215g per nut. As it is sensitive to environmental changes, it has been recommended for planting in home gardens (Wickramaratne 1989).

In India, the production is mostly T x D hybrids and the different forms of Dwarf variety used are the local Orange Dwarf (COD), Green Dwarf (CGD) Gangabondam (GB) and the Malayan Yellow Dwarf (MYD) which had been earlier introduced in the country. The Tall parents belong to West Coast Tall (WCT), Lakshadweep Ordinary (LO), Andaman Ordinary (AO) and East Coast Tall (ECT). T x T hybrids and D x T hybrids are presently produced only in small numbers. The performance of the released coconut hybrids in India were significantly better than the West Coast Tall in terms of nut yield per palm per year (98-140), and except for ECT x MYD, copra yield per palm (16-25 kg) (Nair *et al*. 1996).

In Indonesia, four improved intravarietal hybrids (Kelapa Baru or KB1, KB2, KB3 and KB4) produced by crossing selected Tall cultivars in Kima Atas Experimental Garden have been released. The hybrids started flowering on the 6^{th} year, with total bunches of 16/year, nuts 96-124 palm/year, copra yield 3.88-4.66 t/ha and oil content of 67-71percent.

Another three D x T hybrids evolved from the local material: Khina 1 (Nias Yellow Dwarf x Tenga Tall), Khina 2 (Nias Yellow Dwarf x Bali Tall) and Khina 3 (Nias Yellow Dwarf x Palu Tall) have been released. These hybrids have been found to be superior to the parental types with respect to precocity for bearing and high production of copra (Liyanage *et al.* 1986).

In Cote d'Ivoire, a number of promising hybrids were developed since 1965. Some of the promising D x T combinations produced are Port-Bouet or PB 121 (Malayan Yellow Dwarf x West African Tall), PB 111 (Cameroon Red Dwarf x West African Tall), PB 132 (Malayan Red Dwarf x Polynesian Tall) and PB 122 (Malayan Yellow Dwarf x Polynesian Tall). In the case of PB 121, a yield level of 5.5 t/ha of copra has been recorded. The studies on the comparative performance of the different hybrids conducted at the Marc-Delorme Research Station in Ivory Coast have shown that the productivity of PB 132 is equivalent to that of PB 121 and twice that of West African Tall (Sangare *et al.* 1988). The other promising hybrids PB 122 and PB 111have also been reported to be more precocious and higher yielding than the other local hybrids. The best PB hybrids initiated first flowering 44-57 months after planting, with number of bunches per palm ranging from 12-16, 101-132 nuts/palm, 212-311 g copra/nut and 3.15-4.8 t copra/ha (Bourdeix *et al*. 1993). The T x T combinations such as PB 214 (West African Tall x Vanuatu Tall) and PB213 (West African Tall x Rennel Tall) were also found to be higher yielding than the West African Tall (De Nuce 1989).

In Malaysia, varietal studies commenced in 1920s with Malayan Dwarf forms which showed that Green Dwarfs are robust, resistant to adverse conditions and produce the best quality copra (Jack and Sands 1929 and Jack 1937). The Malayan Green was capable of producing 11.3 kg copra per palm per year, nearly as much as the average Tall palm.

MAWA hybrids (Malayan Yellow, Orange or Red Dwarf x West African Tall combinations) were less variable in terms of nuts/palm, fruit weight and copra weight and, the copra produced has been higher than other hybrids. These MAWA hybrids have been used in the National Planting Programme since 1978. The Malayan Red and Yellow Dwarf x West African Tall have been found to be high yielding (25.82 and 24.98 kg copra/palm, respectively) and the most suitable planting material particularly in the imperfectly drained and highly fertile coastal plains (Chan 1983).

In Papua New Guinea, hybrid seed production was started in 1973. Maren (Malayan Red Dwarf x Rennel Tall) hybrid was released to the farmers in the seventies (Turner 1989). The cumulative yield up to 1982 for Maren was estimated at 11.08 t/ha. However, its field performance has been disappointing to the farmers. It is highly susceptible to the local forms of Rhynchophorus weevil, Scapanes and Rhinoceros beetles. Moreover, the genetic base is also very narrow.

In the Philippines, the hybrids that evolved from the local parental material, namely Catigan Green Dwarf x Laguna Tall and Catigan Green Dwarf x Tagnanan Tall, have been found to be as productive as PB 121 introduced from Côte d'Ivoire. The local hybrids produce bigger sized nuts than PB 121 and also exhibit buffering ability against environmental stress. The local hybrid Catigan Green Dwarf x Laguna Tall has been released as PCA- 15-1 for mass adoption (Santos 1989).

In Jamaica, crop improvement studies were started since 1950 with more emphasis on evolving resistant strains for lethal yellowing disease. All the three Malayan Dwarfs were found to possess a high degree of resistance and only a very small percentage of MYD has been affected by lethal yellowing. The D x T hybrids involving the Malayan Yellow, Green or Red Orange Dwarf and Panama Tall as parents have been found to inherit sufficient immunity to the lethal yellowing disease and also have the capacity for high yield. This hybrid is locally called Maypan (Harries 1971).

In Samoa, Malayan Red Dwarf x Rennel Tall hybrid was produced on a large scale in a coconut seed garden established in 1977 (Efu 1989). Under the FAO Project, the production of open-pollinated MRD x Samoa local Tall was undertaken at Aela where Dwarf palms were planted with local Talls in the surrounding areas. The natural hybrids found in Aela were planted in three locations along with Samoan Tall in 1980.

In Thailand, among the different hybrid combinations tested, PB 121 (MYD x WAT) has displayed greater precocity and has also been found to give more uniform yields than selected Thai Talls. PB 121 was released as Sawi 1 to farmers for general cultivation. Both MYD x WAT and Thai Tall x WAT have been found superior to Thai Tall variety. Two more hybrids, Chumphon Hybrid No. 60 (Maphrao Yai x WAT) and Chumphon Hybrid No. 2 (MYD x Maphrao Yai), were released in the country in 1987 and 1995, respectively.

In Vanuatu, a coconut improvement programme was started during 1962. A number of combinations involving different Talls like Vanuatu Tall, Samoan Tall, Rennel Tall and Rotuman Tall were produced and their field performance was studied under different locations (Calvez 1989). One of the promising combinations, Vanuatu Tall (VTT) x Rennel Tall (RLT), is under field test for tolerance to Foliar Decay disease. Vanuatu Red Dwarf (VRD) x VTT has also been planted in 1984. Initial trials have indicated that T x T hybrids might be superior.

In Tanzania, production of the hybrids MAWA (MYD x WAT) and Camwa (CRD x WAT) was initiated in 1981-1982. However, these hybrids were not different from local East African Tall with respect to tolerance to lethal yellowing and drought.

In Vietnam, high yielding hybrid seednuts were imported in 1985 and the seedlings raised from them were planted in seven different adaptability trial sites in various agroecological zones. The objectives were to evaluate the performance of the imported hybrids in comparison with local ones and to establish trial sites that could also serve as demonstration centres before the hybrids are finally selected and planted on a large scale. The Oil Plant Institute (OPI) subsequently imported four hybrids from Côte d'Ivoire and three more hybrids, JVA I and JVA 2 from the Philippines and CRI 65 from Sri Lanka in 1986 and 1987. These hybrids were planted in different agroecological zones.

The hybrids planted in 1985 had shown higher economic efficiency than the local varieties under the same planting and maintenance conditions. They always had significantly higher values for total nuts, copra and oil than the local Ta and Dau cultivars.

However, higher efficiency was recorded only under favourable conditions of soil, water and maintenance. For the hybrids planted in 1987, flowering and fruiting rates were better than the local varieties (Linh and Long 2000). Among the local varieties, Ta, Dau and Giay have been identified as the best for copra making. A seed garden of 120 ha has also been established at Trang Bang, Tay Ninh Province for producing hybrids and seed material of local varieties.

Other countries

In Fiji, a seed garden is now producing high yielding hybrids using Malayan Yellow Dwarf or Malayan Orange Dwarf with Rennel Tall or Rotuma Tall. In Tonga, a seed garden has been established to produce hybrids. Similarly in Tuvalu, a small seed garden has been operated to produce hybrids of Malayan Yellow Dwarf and Malayan Orange Dwarf with Rennel Tall or with local coconuts. In the Solomon Islands, where controlled pollination began in the 1960's, a replanting programme is being carried out with the Malayan Red Dwarf x Rennel Tall hybrid.

Findings of 1980 and 1988 assessment of new varieties

The Asian and Pacific Coconut Community (APCC) organized two studies in 1980 and 1988. The objective of the first study was to identify the constraints faced by small-scale farmers in the adoption of high yielding varieties with a view to assisting countries to formulate remedial counter measures. The study covered India, Indonesia, Malaysia, Philippines, Papua New Guinea, Solomon Islands, Sri Lanka, Thailand and Western Samoa. The second study in 1988 covered India, Indonesia, Malaysia, Sri Lanka, Papua New Guinea, Philippines and Western Samoa. The objectives of this study were: (1) to identify new technology packages for coconut, (2) to review the state of art of adoption, and (3) to identify reasons for adoption and non-adoption. The findings of these two studies were compiled and released by the APCC (Sumith de Silva 1989).

In India, Indonesia, Philippines, Sri Lanka and Thailand, the number of holdings studied was 223 occupying a total area of 720.9 ha. The average size of a holding in the sample was 3.23 ha. The holdings of less than 2 ha amounted to 58% of the total holdings but occupied only 20.3% of the total area. Holdings above 2 ha and up to 10 ha accounted for 34% of the total holdings with a higher share of 48.4% in the total area. Although holdings above 10 ha formed only 8% of the total holdings, their share in the area was 31%.

Among the cultivars studied, Tall varieties accounted for 27.8%, T x D and D x T hybrids comprised 62.6%, T x T hybrids formed 6.2% and the balance of 3.4% was constituted by miscellaneous other strains. Between T x D and D x T, the latter accounted for 86% of the hybrids spread. The average copra yield during the first 8 years of bearing was 907 kg for Tall, 1352 kg for T x D and 1634 kg for D x T. The unit recovery of copra was, however, high in the Tall which was 4764 nuts to a tonne of copra whereas the corresponding numbers for T x D and D x T hybrids were 7651 and 5825 nuts, respectively. Although the hybrids commenced bearing in the third year as against five years for the Tall varieties, the capital cost and also the recurrent cost were much higher for the hybrids. However, the net returns generated by both the hybrids were higher than that by the Tall variety. Based on their field experience, the farmer participants of the study expressed their opinion about each test material. The study recorded 740 responses of satisfaction for varieties and 457 responses of dissatisfaction. While 28.5% of the respondents expressed preference for Tall varieties, around 43% favoured the existing hybrids while another 28.5% desired to have new varieties possessing better qualities. Higher yield, early bearing, ease to harvest, vigour, uniformity, superior quality copra, higher income, etc. were the notable benefits observed by the farmers who were satisfied with the performance of hybrids, particularly the D x T.The reasons expressed for dissatisfaction were: less than expected yield, vulnerability to diseases and pests, small nuts, low prices, low income, etc., in case of hybrids; and low yield, non-uniformity, late bearing and low income in case of Talls.

The farmers' views on new varieties were not significantly different in most countries. In India, of the two hybrids, farmers favoured only D x T. Even in this case, one hundred percent acceptance was not reported by the farmers. Only 50% of the farmers were satisfied with the performance of T x D. More than 50% of the farmer participants of the study preferred the traditional Tall variety for future planting. About 30% preferred D x T and other tested hybrids and the balance desired to have new (not yet tried) varieties.

In Indonesia, field survey revealed that 78% of the farmer participants were satisfied with the performance of hybrids mainly due to their early bearing and high yielding characteristics. The remaining respondents were not satisfied because of the higher cost involved in the use of fertilizers and other inputs, the yields realized were less than expected, small size of nuts and immature nut fall.

In Malaysia, survey results indicated that the yield increase in terms of number of nuts obtained by the farmers from hybrids was more than 200%. But the corresponding increase in net income was not materialized due to escalating cost of production. Although the Mawa hybrids yielded larger number of nuts, the nut size was small causing higher cost of producing copra on per unit basis. As such, increase in the number of nuts has not produced a proportionate increase in the farmers' income.

In Papua New Guinea, the hybrids were highly susceptible to the local strains of Scapanes and Rhinoceros beetles and Rhynchophorus weevil. The hybrid programme in PNG had to be suspended pending a solution to the pest problem.

In the Philippines, about 55% of the farmer respondents expressed satisfaction with hybrids due mainly to early bearing characteristic and compatibility with the environment. The dissatisfied farmers (45%) cited high fertilizer cost and lower realization of yield than expected, as the reasons.

In Sri Lanka, both CRIC 65 and CRIC 60 were found suitable only to certain parts of the country. However, the planting material of the hybrids was distributed indiscriminately with the result that the performance was not up to expectation in unsuitable locations. In the field survey, 66.7% of the farmer participants were satisfied with T x T hybrids and only 16.7% were satisfied with the intervarietal hybrids or D x T hybrids.

The study conducted in Thailand showed that the majority of the farmer participants favoured the hybrid due to its vigorous growth, uniformity and consistency in yield, early bearing characteristics and its adaptability to a wide range of environment. The dissatisfaction expressed by others was due to smaller fruit size which, due to its low market price, results in low income to the farmers. The hybrid Sawi 1 gave the lowest direct income while the top earner, Thai Tall, generated income double that of Sawi 1. The difference was due to the higher unit income for mature nuts of Talls in the local market.

Summary of major findings of the 1998 varietal assessment study

A more comprehensive varietal assessment study was initiated in 1998 in the member countries of the Asian and Pacific Coconut Community (APCC) and of the International Coconut Genetic Resources Network (COGENT) with the financial support of COGENT and the Bureau for the Development of Research on Tropical Perennial Oil Crops (BUROTROP) and APCC. In several countries, either the study was not completed or the final reports were not prepared. Consequently, this paper has been prepared based on the completed reports received from the following 10 countries (examinant countries): Brazil, Cote d'Ivoire, Federal States of Micronesia, Fiji, Indonesia, Jamaica, Malaysia, Mexico, Papua New Guinea, Philippines, Samoa, Sri Lanka, Tanzania, Thailand, Vanuatu and Vietnam. The samples for the study were drawn in each country from three distinct agroclimatic zones: wet, intermediate and dry.

Size class distribution of sample holdings

The details of the distribution of the sample farms according to size in India, Philippines, Samoa, Sri Lanka, Thailand and Vietnam are given in Table 1.

Table 1. Size and class distribution of the sample farms*

Size Class (ha)	No. of Farms	Extent (ha)	Average Size of Farm (ha)	% of Farmers	% of Area	No. of Farms by Zone		
						Wet	Intermediate	Dry
< 1.0	113	49.29	0.44	23.70	4.57	50	49	14
1-2	73	100.29	1.37	36.69	9.29	30	30	13
2-4	52	162.43	3.12	16.88	15.05	18	17	17
4-6	28	144.39	5.16	9.09	13.37	14	6	8
6-8	13	88.62	6.80	4.22	8.20	4	5	4
8-10	9	82.60	9.17	2.92	7.65	4	4	1
10-20	19	380.00	20.00	6.18	35.20	4	13	2
Above 20	1	72.00	20.00	0.32	6.67	-	1	-
Total / Average	**308**	**1079.62**	**3.50**	**100.00**	**100.00**	**124**	**125**	**59**

* *In India, Philippines, Samoa, Sri Lanka, Thailand and Vietnam*

The average size of the sample farms in the six countries was 3.5 ha with a range of 0.44 to 20 ha. The total area covered by all the farms was 1079.62 ha. The farmers possessing below 2 ha formed over 60% of the sample although their share in the total area was only below 14%. On the other hand, farmers with area above 2 ha but below 8 ha formed around 30% but commanded over 36% of the total area. At the same time, the farmers who had farms of the size between 8 and 20 ha had a share of over 42% in the total area although they formed only 9% of the total number of farmers. Of the total 308 farms in the sample, 124 or 40% were in the wet zone, 125 or 41% fell in the intermediate zone and 59 or 19% represented the dry zone.

Age at first fruiting and productivity

The age at first fruiting and the annual production of nuts and copra varied between varieties and the agroclimatic zones as shown in Table 2.

The general trend was that the hybrids came into early bearing in the wet zone although exceptions were observed in some countries. Irrespective of the growing zones, the average pre-bearing period for D x T and T X D hybrids observed in India, Sri Lanka and Vanuatu were 4.4 and 4.7 years, respectively. In the case of T x T hybrids in Sri Lanka and Vanuatu, the average fruit initiation was 5.8 years. Selected local Talls in the Philippines, Vanuatu and Vietnam, started bearing fruits at an average of 5.5 years while the Malayan Dwarfs of Jamaica and selected Dwarfs of Vietnam were more precocious with an average bearing age of 3.7 years.

In India, the production of nuts and copra was highest for T x D hybrid in the wet zone, but was such only in terms of nuts in the intermediate zone. For D x T hybrid, the production of nuts as well as copra output was much higher in the intermediate and dry zones than in the wet zone. The difference in the production between T x D and D x T revealed the preference of the former for more favourable soil moisture relations.

In Indonesia, the performance of Mawa hybrid was recorded in the wet zone and that of Nias Yellow Dwarf hybrid (NYD x WAT) in the intermediate zone. Since their agronomic performances were observed under different zone conditions, their optimum growing conditions for maximum productivity has not been elucidated.

The Malayan Dwarf variety and the Maypan hybrid were compared under the different zones in Jamaica. In all the three zones, the Malayan Dwarf outperformed the hybrid in precocity of bearing, as well as in the production of nuts and copra. Productivity in terms of nuts and copra output was also higher for the Malayan Dwarf compared with the Maypan hybrid through all the zones. The Dwarf variety and hybrid showed preference for wet agroclimatic zone to maximize production.

In the Philippines, the two Tall types (Laguna and Tagnanan) , and two hybrids (Mawa and PCA 15-1) exhibited better productivity in the wet zone than in the other two zones with the lowest in the dry zone indicating the sensitivity to soil moisture stress. Between the two hybrids, PCA 15-1 was found to be superior to Mawa in all the three zones.

One significant observation recorded in the Philippines studies was the better productivity of Laguna Tall compared to the two hybrids in all the three zones. Hence, the Laguna Tall cultivar is a better option for planting in the wet, intermediate and dry zones.

In Sri Lanka, the D X T showed preference for the dry zone. When compared with San Ramon x Dwarf, the latter yielded better in the intermediate zone but production figures for the other two zones were not available for this hybrid. The data for T x D hybrid were available

Table 2. Average production and bearing time

Country & zone	Variety	Years to bearing	Nuts per ha	Nuts/t copra	Copra/ ha (t)
INDIA					
Wet	T x D	4.1	14 832	5962	2.49
	D x T	5.0	13 366	6300	2.12
Intermediate	T x D	4.4	18 187	7802	2.33
	D x T	4.6	17 627	5861	3.00
Dry	T x D	4.8	10 111	5925	1.71
	D x T	4.5	11 844	5440	2.17
INDONESIA					
Wet	Mawa hybrid	3.8	12 444	5447	2.28
Intermediate	NYD x WAT	4.0	11 277	6200	1.82
JAMAICA					
Wet	Tall	-	5850	3500	1.67
	Malayan Dwarf	3.3	20 588	6277	3.28
	Maypan hybrid	4.1	12 775	4125	3.10
Intermediate	Tall	-	-	- -	
	Malayan Dwarf	3.3	13 013	5733	2.27
	Maypan hybrid	4.5	6230	3785	1.65
Dry	Tall	-	-	- -	
	Malayan Dwarf	3.3	18 545	6440	2.88
	Maypan hybrid	4.4	11 527	4388	2.63
PHILIPPINES					
Wet	Laguna Tall	6.0	11 214	3528	3.18
	Tagnanan Tall	6.0	7342	2738	2.68
	Mawa hybrid	4.0	11 351	4087	2.78
	PCA15-1 hybrid	4.0	10 624	3368	3.15
Intermediate	Laguna Tall	6.0	11 214	4151	2.70
	Tagnanan Tall	6.0	6465	3221	2.00
	Mawa hybrid	4.0	9849	4809	2.05
	PCA15-1 hybrid	4.0	9276	3963	2.34
Dry	Laguna Tall	5.0	9528	4744	2.00
	Tangnanan Tall	5.0	5460	3704	1.47
	Mawa hybrid	4.0	7029	5530	1.27
	PCA 15-1 hybrid	4.0	8366	4557	1.84
SRI LANKA					
Wet	T x T	6.2 5	4492	5500	0.82
	D x T	4.70	8415	6000	1.40
Intermediate	T x T	-	10 620	- -	
	San Ramon x D	6.0	12 883	- -	
	D x T	4.0	7952	4360	1.82
	T x D	5.5	10 166	4400	2.31
Dry	T x T	5.0	9575	5000	1.92
	D x T	4.0	9106	- -	
SAMOA					
Wet	Tall	6.0	4006	5053	0.79
	Hybrid	3.5	6694	4687	1.43
Intermediate	Tall	5.6	3860	5053	0.76
	Hybrid	3.5	7649	4687	1.63
VANUATU					
	Local Tall	5.0	9620	6013	1.60
	Improved Tall	5.0	11 840	5382	2.20
	T x T	6.0	12 580	4341	2.90
	D x T	4.0	23 200	6629	3.50
VIETNAM					
Wet	Tall	5.4	4903	4064	1.21
	Dwarf	3.7	19 456	- -	
	Hybrid	4.0	5364	5000	1.07
Intermediate	Tall	5.25	7375	4265	1.73
	Dwarf	5.0	26 667	- -	
	Hybrid	3.5	6195	5500	1.13
Dry	Tall	5.0	5360	5188	1.03

only for the intermediate zone which showed higher productivity than those of D x T hybrid. The T x T performed well under the intermediate and dry conditions but had the least number of nuts and copra yield among the test materials when planted under the wet zone.

In Samoa, the hybrid yield was more than that of Tall in both the wet and intermediate zones. The average productivity of hybrid through the two zones was 7172 nuts or a copra equivalent of 1.53t against 3933 nuts or 0.78 t of copra/ha/year of the Tall.

Differential performance of local Tall, improved Tall, T x T and D x T was recorded in Vanuatu for only one zone. The performance of D x T was found to be far superior compared with all the other types in terms of precocity, number of nuts and copra output.

The Dwarf types produced significantly more nuts/ha compared with the hybrid and Talls in Vietnam. The Dwarf variety yielded profusely in the wet and intermediate zones but its production figures for the dry zone were not recorded. Further, its fruits were mostly consumed as tendernut.

Farmers' evaluation of coconut cultivars

The farmers covered in this study were individually contacted and their observations on each cultivar including their satisfaction or otherwise and varietal preferences were recorded. A total of 851 responses of satisfaction were recorded with 599 or 70% in favour of T x D and D x T hybrids. High yield, early bearing and good nut size, were the major reasons for satisfaction with the hybrids. This was followed by the Dwarf with 128 or 15% favourable responses and the most preferred traits were better resistance to pests and diseases, high yield, easy marketability and early bearing. The Tall cultivars including the T x T hybrids were preferred for thick kernel and cream, high yield and miscellaneous other traits. The number of responses in their favour was 124 or 14.5%. The specific reasons for satisfaction of farmers with each cultivar are shown in Table 3.

The study also recorded 339 responses of dissatisfaction with the varieties already experienced by the farmers. Out of the total, 235 or nearly 70% responses of dissatisfaction were with T x D and D x T hybrids and the major reasons made known by the farmers were small size of nuts, bunch buckling, high input requirement, vulnerable to moisture stress, vulnerable to pests and diseases, low yield, less creamy kernel, alternate bearing, etc. There were 67 responses of dissatisfaction with Dwarf variety but only 36 such responses were recorded in the case of Tall variety. The major reasons for dissatisfaction with Dwarf variety were small nuts, difficult to market, pilferage, etc. The major reason expressed against the Tall variety was its late bearing tendency.

Table 3. Reasons for satisfaction by cultivar (no. of responses)*

Reasons	Tall	TxD/ DxT	TxT	Dwarf	Total
High yield	31	153	8	30	222
Early bearing	11	137	1	23	172
Good nut size	-	119	-	-	119
Thick kernel/high copra content	40	28	-	-	68
Ease of scraping	-	11	-	-	11
Thick cream with good flavour	10	9	-	-	19
High oil content	-	8	-	-	8
Good toddy yield	6	4	-	-	10
Sweet tendernut water -	20	-	-	-	20
Low incidence of bunch buckling	6	-	-	-	6
Short & strong fronds -	-	-	-	-	-
Better resistance to pests and diseases	2	48	-	38	88
Medium/short stature-	12	-	-	-	12
Long life span	6	-	-	-	6
Low maintenance costs-	1	-	-	-	1
Easy marketability	-	29	-	23	52
Good timber	1	-	-	-	1
High frequency of harvest	-	-	-	11	11
Others	2	20	-	3	25
Total	**115**	**599**	**9**	**128**	**851**

**The Philippines and Vanuatu were not included due to lack of quantified data*

Varietal preference of farmers

The farmers in the surveyed farms were asked to indicate the varieties preferred by them for planting, if another chance arises. To this inquiry, 381 quantified responses were received from India, Indonesia, Jamaica, Samoa, Thailand and Vietnam. The results are given in Table 4.

Of the total 381 responses, 55.6% were in favour of hybrids and 28% in favour of the local and / or selected Talls. In Indonesia, where hybrids have already spread to a large extent, only 5.56% of the farmers wanted to plant the same coconut hybrids while 94.44% of the farmers opted for selected local Talls and locally produced hybrids for planting the next time. In India, 59% of the farmers preferred selected Talls and only 41% expressed preference for hybrids. In Sri Lanka, only 53% of the farmers having experience with D x T expressed the desire to plant the same hybrid whereas, 55% of the T x T growers were completely satisfied with the variety and were willing to plant the same if given a second chance.

In Samoa, all the farmers covered in the survey stated that they will grow the hybrid, given a second chance. Out of these farmers, 47% also wanted to grow the local Tall besides the hybrid. In Thailand, 70% of the farmers remained satisfied with the hybrids and the rest preferred to plant Tall variety. The variety preferred by 54% of the farmers in Vietnam for planting, given a second chance, was the local Tall. Only 26% of the farmers wanted to grow hybrid and the balance 20% stated that they would grow the local Dwarf cultivar, Xiem.

Table 4. Farmer's preference of cultivars, given a second chance (no. of responses)

Zone	Local /Selected Tall	Hybrids	Dwarf	Total
Wet	31	91	43	165
Intermediate	59	75	8	142
Dry	18	46	10	74
Total	**108**	**212**	**61**	**381**

Conclusion and recommendations

Hybrid seed production has a history of 3-6 decades in most of the coconut growing countries. In countries like India and Sri Lanka, the programme has been continuing since 1940's and in Côte d'Ivoire it was commenced in 1951. Hybrid combinations were evolved and planted in the research institutes at the first stage and at farmers' fields later under diverse agroclimatic conditions. The performance of hybrids was good in terms of nut and copra yield besides early bearing, vigorous growth and uniformity in yield, particularly in D x T. The farmers' response was varied since they are not very clear about the required input management to maximize yields for coconut in general and high yielding varieties and hybrids in particular. The APCC studies of 1988 and 1998 have, however, revealed that the level of acceptance of T x D and D x T hybrids has been lagging below expectation despite their potential for early bearing and higher production. These hybrids exhibited certain undesirable traits which were not appreciated by the farmers.

By and large the hybrids under favourable weather and optimum management conditions have performed better than the local Tall. But experience in some countries showed that even under intensive management, the hybrids do not perform better than the local Tall cultivars growing under the same conditions. In Vietnam, the performance of hybrids in terms of copra production under the intensive management category was not as much as the local Tall cultivars by the eight year after coming into production. The same trend was observed in Sri Lanka. These results highlight the fact that the productivity of some of the hybrids, even under intensive management, is not significantly different than those of selected Tall varieties; and that the production technology of hybrids has to be improved if farmers are to be benefited from their cultivation.

Except, perhaps, in Côte d'Ivoire, the production of hybrids in most other countries has been organized without developing adequate populations of strains or ecotypes tested for specific combining ability. The general combining ability of the existing varietal forms is presently the yardstick for the production of hybrid combinations, which invariably show differential performance and exhibit undesirable traits when grown under field conditions. There is a scope for identifying ecotypes possessing superior traits from among the available cultivars and testing them for both general and specific combining abilities with other strains or ecotypes. The populations comprising selfed progenies of those ecotypes, proven to be the best combiners when established, can serve as the basic material for evolving better hybrids. It is not difficult to identify special strains or ecotypes in each country through participatory approach.

Among the countries where coconut hybrids have been introduced, Indonesia appears to have taken the lead with having 244 310 ha under hybrids in 1996 with the estimated production of 121 729 t of copra per year, which is only 50% of the average productivity of the Tall variety in that country. Therefore, when farmers in that country are given the opportunity to plant coconuts again, only 5.56% of them wanted to plant the introduced hybrids, while 94.44% of the farmers wanted to plant selected local Talls, T x T hybrids and the locally produced Khina hybrids. The experience in most of the countries is that the intervarietal hybrids perform well only under intensive management hence, their poor adoption by the small- and medium-scale farmers who are not used to high external input farming in coconut. As long as the new hybrids are not amenable to low external input farming, the farmers may not opt for them either for new planting or replanting. Appropriate breeding technology has to be perfected for producing hybrids possessing potential for higher productivity under average management without exhibiting undesirable traits.

Based on the results of the trials, the following recommendations are made:

1. Ecotypes possessing favourable traits should be identified in each country through participatory approach. These ecotypes should be crossed with selected cultivars and the best combiners identified through progeny testing. The parents of the promising crosses

should be multiplied by selfing to raise a sizeable population of selfed progenies for large-scale reproduction of the best crosses.

2. The performance of high yielding varieties should be satisfying to small and medium-scale farmers under low external input situations. T x T combinations amenable to such situations should be produced by crossing genetically superior Tall palms which normally constitute 3-5% of the palm population in any holding.
3. The Malayan Green Dwarf, which under Malaysian conditions proved to be better than the yellow and red colour forms in productivity, resistance to pests, diseases, and adverse conditions as well as in vigour and robustness, should be utilized as one of the parents in cross breeding. The resulting progenies should be tested for their yield performance.
4. Coconut farmers should be trained on the appropriate care and management of high yielding varieties and hybrids in coconut plantations, and should be educated on the benefits they could get in terms of increased yield and returns.
5. Production of quality planting materials of selected Talls, Dwarfs and hybrids should be augmented and made available to the farmers in adequate quantity.

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Multilocation coconut hybrid trials in three African and three LAC countries

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Introduction

The main objectives of the multilocation trials are: 1) to assist each of the six participating countries in identifying suitable high-yielding varieties/ hybrids with high adaptation to prevailing local conditions; and 2) to estimate genotype x environment (G x E) interaction, which will serve as a guide to the application of the results to other countries with similar growing conditions.

Each test country compared the six common multi-site hybrids produced and shipped from Côte d'Ivoire with 4-8 of its best hybrids/ varieties. The imported hybrids are four Dwarf x Tall and two Tall x Talls which have been proven to have good yield potential in previous trials. Each experimental unit or plot consisted of 16 palms, planted in a triangular pattern at 9m in a randomized complete block design (RCBD) with five replications. When sufficient vegetative and reproductive data will have been generated, statistical analysis shall be done at country level to compare the different genetic materials, while a combined data analysis will be conducted to determine the interaction between genotype and environment.

Project implementation

The project was approved by the Common Fund for Commodities (CFC) Executive Board on 22 October 1996 and funds were released to IPGRI in January 2000. However, the six participating countries and IPGRI prefinanced the project from 1997 to 1999 to fund preparatory activities in support of the project.

The implementation of this multilocation trial to evaluate the performance of 30 imported and local coconut hybrids and varieties, and their G x E interaction involved three African countries (Côte d'Ivoire, Benin and Tanzania) and three Latin American and Caribbean or LAC countries (Brazil, Jamaica and Mexico). Six promising hybrids (MYD x WAT, CRD x RIT, VTT x TAGT, MRD x VTT, MRD x TAGT and SLT x TAGT) were produced by Côte d'Ivoire and air-shipped to the five participating countries (one set was retained for the Côte d'Ivoire trial) while the six participating countries produced seednuts of their promising local hybrids/varieties to serve as controls. The 30 initial coconut hybrids/ varieties that were identified to be produced and tested in the multilocation trials are shown in Table 1.

The six countries originally planned to produce four local hybrids each to be compared with the six common imported hybrids. However, this target output was exceeded because Mexico produced four additional local hybrids, namely: MYD x $MXPT_{05,}$ MYD x $MXPT_{10,}$ MYD x $MXPT_{11}$ and MYD x MXAT.

All six countries conducted two trials each, the first, a general performance trial using the seedlings from the first batch of hybrid seednuts sent from Côte d'Ivoire and the locally produced hybrids/ varieties; and the second, using the second and third batch (only for Brazil) of seednuts from Côte d'Ivoire.

Table 1. List of multi-site and local hybrid/variety trial entries

A. Six multi-site hybrids (common for all participating countries)			
Dwarf x Tall hybrids (4)		**Tall x Tall hybrids (2)**	
MYD x WAT	CRD x RIT	VTT x TAGT	
MRD x VTT	MRD x TAGT	SLT x TAGT	

B. Four locally-selected materials per country					
Côte d'Ivoire	**Bénin**	**Tanzania**	**Jamaica**	**Mexico**	**Brazil**
MYD x TKT	MYD x PNT	EAT o.p.	MYD x THT	MYD x PNT	BGD x VTT
MYD x TGT	CRD x WAT	PRD x EAT	MYD x PNT	MYD x $MXPT_{14}$	BGD x BRT
MYD x PUT	CRD xT AT	EAT x RIT	CGD x PNT	MYD x $MXPT_{09}$	MYD x BRT
PGD x VTT	PGD x VTT	EAT x VTT	CGD x THT	MYD x $MXPT_{02}$	BRT o.p.
				(+ 4 additional hybrids)	

List of variety names			
BGD	Brazilian Green Dwarf	o.p.	open pollinated
CRD	Cameroon Red Dwarf	PYT	Polynesia Tall
CUD	Cuban Dwarf	BRT	Brazilian Tall
FJM	Fiji Malayan Dwarf	PNT	Panama Tall
MRD	Malayan Red Dwarf	RIT	Rennell Island Tall
MYD	Malayan Yellow Dwarf	SLT	Sri Lanka Tall
PRD	Pemba Red Dwarf	TAG	Tagnanan Tall
EAT	East African Tall	THT	Thailand Tall
WAT	West African Tall	VTT	Vanuatu Tall
PGD	Pumila Green Dwarf	CGD	Chowghat Green Dwarf

Noting the potential impact of this project in increasing the yields of poor coconut farmers, the Government of Portugal funded a similar project involving the evaluation of the same six multi-site hybrids and four local hybrids (MYD x MZT, BGD x RLT, MZT x SGD and MZT x VTT) in Mozambique. This brought to 38 the total number of coconut hybrids/ open-pollinated varieties being evaluated, making this project the most comprehensive coconut hybrid trial worldwide.

The details of the multi-location trials are presented in CFC Technical Paper No. 42 entitled, 'Coconut Hybrids for Smallholders' (Batugal *et al.*, eds 2005).

Major achievements

The most important result of the project is the identification of 16 early bearing and high-yielding new coconut hybrids (Table 2). The first trial showed that 16 out of the 34 test trials in the CFC-funded project started to flower and produce fruits in Brazil, Jamaica and Mexico in 2.5-3.0 years after planting compared to the seven years it would normally take the traditional Tall varieties to reach fruiting stage. In Brazil, two hybrids from Côte d'Ivoire and two local hybrids flowered; in Jamaica, all six hybrids produced in Côte d'Ivoire flowered but none of the local hybrids; while in Mexico, only one hybrid produced in Côte d'Ivoire and eight locally produced hybrids flowered. On the other hand, flowering was not observed in the hybrids planted in Benin, Côte d'Ivoire and Tanzania during the same period. These results suggest that the drought in Africa and the generally drier conditions in that region compared to the LAC region had a negative effect on early flowering of the hybrids, suggesting a possible G x E interaction. This interaction could be verified with the vegetative and reproductive plant measurements and biotic and abiotic data to be gathered and analyzed in the next five years.

Based on the yield projection of the potential of the 16 fruiting hybrids on their fourth year (as observed in preliminary trials), they have the potential to produce up to five tonnes of copra (dried kernel) per hectare per year at the peak of production (at 10-12 years) compared to the one metric tonne of copra generally produced by the traditional Tall cultivars. The impact of the results from this CFC-funded project is significant as it has the potential to increase coconut yields of resource-poor smallholder coconut farmers by up to five-fold if the results are effectively promoted, with good management, in many coconut growing communities and countries. Although the hybrids in the second trial are all growing well in five countries (except Benin), the potential of the hybrids could only be determined when they start to produce fruits three more years after the project termination.

Table 2. Coconut hybrids that started fruiting 2.5 - 3.0 years after planting (with check)

Hybrids produced in Cote d'Ivoire	Brazil	Mexico	Jamaica
MYD x WAT	☑	☑	☑
MRD x VTT			☑
CRD x RIT			☑
MRD x TAGT	☑		☑
SLT x TAGT			☑
VTT x TAGT			☑
Locally produced hybrids			
MYD x $MXPT_{05}$		☑	
MYD x MXAT		☑	
MYD x $MXPT_{10}$		☑	
MYD x $MXPT_{11}$		☑	
MYD x $MXPT_{02}$		☑	
MYD x $MXPT_{09}$		☑	
MYD x $MXPT_{14}$		☑	
MYD x PNT		☑	
BGD x BRT	☑		
BGD x VTT	☑		

In Tanzania, although the few seedlings planted from the first batch of seednuts did not grow well due to drought, fire and termite infestation, the seedlings in the second replicated trial were very robust and were growing very well and are expected to flower within the next 24 months. In Côte d'Ivoire, both the seedlings in the first and second batches of seednuts are growing well. Oryctes beetle infestation is under control through a good integrated pest management system. In Benin, the plants from the first batch of seedlings did not do very well due to severe drought while the plants in the second batch are growing well in the three blocks (replications). The two blocks located in the low-lying area of the experimental field were waterlogged and remedies are being made to construct a drainage system.

In Jamaica, the plants in the second trial are growing well, despite some damage by the lethal yellowing disease. In Brazil, the plants in the second batch are growing well except for a few missing hills which were replanted.

Capacity building

The second most important achievement of the project is capacity building. Based on all project components, 182 coconut researchers participated in 15 training courses and 863 attended various meetings, conferences and workshops for a total of 1045 coconut researchers worldwide whose research capacities have been enhanced (Annex 1). These events allowed coconut researchers and officers worldwide to enhance their skills on coconut genetic resources research and shared expertise, experiences and ideas to address common problems and

Reference

opportunities affecting the farmers and the coconut industry. These capacity building activities have strengthened the research capability of coconut producing countries and promoted inter-country and inter-regional collaboration for conducting research to help resource-poor coconut farmers.

The results of training for the CFC-funded components of the project are shown in Table 3. The project exceeded the target outputs by 42 (number of trained researchers) based on the conducted training activities. However, because training on molecular techniques for pathogen characterization was already programmed in the newly approved CFC-funded project on lethal yellowing disease, training on (GxE) interaction analysis was substituted which was identified by the project participants as a priority activity to expand the application of project results in various environments across the world.

Table 3. Trained coconut researchers from national programmes based on target outputs of the CFC-funded project

Target output of CFC-funded training component	Actual output	Excess over target output
40 coconut breeders from 30 countries trained in breeding research techniques	50 coconut breeders from 30 countries trained in breeding research techniques	+ 10 coconut breeders
30 germplasm workers from 30 countries trained in collecting and conservation	45 germplasm workers from 30 countries trained in collecting and conservation	+ 15 germplasm workers
15 biotechnologists from 10 countries trained in molecular techniques for diversity assessment	18 biotechnologists from 9 countries trained in molecular techniques for diversity assessment	+ 3 biotechnologists
30 physiologists from 15 countries trained in embryo culture techniques	42 physiologists from 15 countries trained in embryo culture techniques	+12 physiologists
10 researchers from 5 countries trained in cryopreservation techniques	12 researchers from 5 countries trained in cryopreservation techniques	+ 2 researchers
10 researchers from 5 countries trained in molecular techniques for pathogen characterization	Not done but training on Germplasm x Environment Interaction analysis involving 9 participants was substituted	-

Reference

Batugal, P, D Benigno and J Oliver (eds). 2005. Coconut hybrids for smallholders. CFC Technical Paper No. 42. CFC/IPGRI. 235p.

Annex 1. Training and capacity building activities conducted under the CFC-funded multi-location coconut hybrids trial project

Training and capacity building activities	Description	Venue	Dates	No. of participants
A. TRAINING COURSES				
The Sub-Regional STANTECH Training Course for Africa	Training on aspects of coconut germplasm collecting, conservation and documentation, and breeding techniques	Station Cocotier Marc Delorme Abidjan, Côte d'ivoire	16-26 June 1997	9
Regional STANTECH Training Course For Latin America And The Caribbean	Training on aspects of coconut germplasm collecting, conservation and documentation, and breeding techniques	Coconut Industry Board (CIB) Kingston, Jamaica	14-25 July 1997	6
Coconut Germplasm Collecting and Conservation Training Course	Training on aspects of coconut germplasm collecting and conservation techniques	Philippine Coconut Authority (PCA) Zamboanga, Philippines	1-12 Sep 1997	11
International Coconut Embryo Culture and Acclimatization Workshop	Assess and upgrade and standardized embryo culture technology	Albay Research Center Philippine Coconut Authority Philippines	27-31 Oct 1997	14
Coconut Multilocation Hybrid/Variety Trials Workshop	Workshop to identify suitable hybrids and varieties for Africa, Latin America and the Caribbean	Station Cocotier Marc Delorme Abidjan, Côte D'ivoire	10-12 Nov 1997	9
STANTECH Training Course on Collecting and Management Of Coconut Genetic Resources	The training course focused on coconut genetic resources collecting strategy, the collecting process and the methods of descriptions of coconut varieties	Vanuatu Agricultural Research and Training Center (VARTC) Santo, Vanuatu	29 Jun – 10 Jul 1999	4
Second International Coconut Embryo Culture Workshop	Assess and upgrade and standardized embryo culture technology	Centro de Investigacion Cientifica de Yucatan (CICY) Merida, Mexico	14-17 Mar 2000	28
Regional Training Course On *In Vitro* Conservation and Cryopreservation On PGR	Training on Coconut Cryopreservation	NBPGR, India	12-25 Oct 2000	7
STANTECH Training Course	The training course used the standardized techniques as guidelines in coconut breeding and germplasm conservation with the hope that it will help coconut researchers obtain better and comparable results	Philippine Coconut Authority-Zamboanga Research Center, San Ramon , Zamboanga City Philippines	2-7 April 2001	6
2nd CFC-Funded Project Workshop and Initial Consultation on a Proposed Globally Coordinated Coconut Breeding	Consultations to refine the proposed globally coordinated coconut breeding programme	Mikocheni Agricultural Research Institute (MARI) Dar es Salaam, Tanzania	11-12 June 2001	39
Standardized Research Techniques in Coconut Breeding	Training on coconut germplasm characterization and seednuts production (controlled and assisted pollination in seed-garden).	CNRA Marc-Delorme Côte d'Ivoire	16-28 Jan 2002	2
Workshop on Coconut Genetic Resources Management Using Microsatellite Kit and Dedicated Statistical Software	Training on using Microsatellite Kit and Dedicated Statistical Software	CIRAD Montpellier, France	15-24 Apr 2002	18

Coconut Cryopreservation Training Course	Training on Coconut Cryopreservation	Institut de Recherche pour le Développement (IRD) Montpellier, France	13-17 Oct 2003	5
Technical writing, seminar presentation, public awareness and proposal preparation	Training course on technical writing, seminar presentation, public awareness and proposal preparation	Merida, Mexico	6-7 Nov 2003	15
Statistical Design and Germplasm x Environment Interaction Analysis Training Course	To acquaint training course participants with the various statistical designs and methods of data analysis that could be used for coconut research and the protocol for G x E interaction	Hotel Grand Maya, Kuala Lumpur	25-27 Nov 2004	9
Subtotal for Training				***182***
B. WORKSHOPS AND MEETINGS WITH INVITED SPEAKERS FROM ADVANCED LABORATORIES AND PRODUCER COUNTRIES				
Cadang-cadang viroid-like sequences meeting	Consultation on the Cadang-cadang viroid-like sequences	Serdang, Malaysia	21-23 Apr 1997	14
LAC coconut regional project proposal formulation meeting	Initial consultation to refine an LAC coconut regional project proposal	Kingston, Jamaica	7-12 July 1997	7
Coconut Genetic Resources Network In Asia and the Pacific Region (CGRNAP) Phase 1/Phase 2 annual Review and Planning Meeting	Review the progress of the conservation and utilization of the coconut genetic resources project and work plans	Bogor, Indonesia	15-17 Sep 1997	28
Annual meeting, Coconut multi-purpose uses project	Review the progress of the coconut multipurpose uses project and work plans	Bogor, Indonesia	18-20 Sep 1997	28
6th COGENT Steering Committee meeting	Review the progress of COGENT and work plans	Port Bouet, Côte d'Ivoire	13-15 Nov 1997	14
ADB-Funded Projects Annual Meeting	Review the progress of the germplasm collecting and conservation project and work plans	Kuala Lumpur, Malaysia	29-31 Oct 1998	29
IFAD-Funded Projects Annual Meeting	Review the progress of the coconut multipurpose uses project and work plans	Kuala Lumpur, Malaysia	2-4 Nov 1998	21
International Coconut Genebank Workshop	Review the progress of the field and regional genebanks project and work plans	Madang, Papua New Guinea	6-7 Nov 1998	20
7th COGENT Steering Committee meeting	Review the progress of COGENT and work plans	Madang, PNG	9-11 Nov 1998	20
IFAD-funded project meeting	Review the progress of the coconut multipurpose uses project and work plans	Ho Chi Minh city, Vietnam	13-15 Sep 1999	27
ADB Phase 2 project meeting	Review the progress of the germplasm collecting and conservation project and work plans	Ho Chi Minh City Vietnam	16-17 Sep 1999	27
COGENT Steering Committee meeting	Review the progress of COGENT and work plans	Ho Chi Minh City , Vietnam	20-22 Sep 1999	16
2nd International Coconut Embryo Culture Workshop	Review the progress of the project and work plans	Merida, Mexico	14-17 Mar 2000	28

Meetings of ADB/IFAD Funded Coconut Research Projects and Future Directions of the Coconut Industry in the South Pacific	Review the progress of the collecting/ conservation and multipurpose uses project and work plans	Apia, Samoa	26-30 Jun 2000	20
ADB & IFAD Funded Projects Joint Annual Meeting for Asia	Review the progress of the collecting/ conservation and multipurpose uses project and work plans	Manila, Philippines	10-15 July 2000	21
International Coconut Genebank Workshop	Review the progress of the project and work plans	Chennai, India	17-19 July 2000	24
9th COGENT Steering Committee Meeting	Review the progress of COGENT and work plans	Chennai, India	20-22 July 2000	24
International Coconut Conference	Review the progress of the coconut genetic resources and work plans	Chennai, India	24-28 July 2000	167
CFC project workshop	Review the progress of the multilocation coconut hybrid trials project and work plans	Dar es Salaam, Tanzania	11-12 Jun 2001	22
10th COGENT Steering Committee meeting	Review the progress of COGENT and work plans	Dar es Salaam, Tanzania	13-15 Jun 2001	22
Poverty Reduction in Coconut Growing Communities, Project Inception and Stakeholders' Meeting	Initial consultation on a proposed project proposal	Ho Chi Minh City, Vietnam	25 Feb-1 Mar 2002	25
11th COGENT Steering Committee meeting	Review the progress of COGENT and work plans	Bangkok, Thailand	25-28 Jun 2002	20
CFC Mid Term Evaluation Project Meeting	Review the mid-term progress of the CFC-funded project and work plans	Kingston, Jamaica	25-27 July 2002	15
2nd International Coconut Genebank (ICG) Meeting and Consultation on Proposed Globally Coordinated Coconut Breeding	Review status of the ICGs and consultations on a proposed project proposal	Kasaragod, India	30 Oct-1 Nov 2002	31
2nd Annual ADB funded Project Meeting	Review the progress of the poverty reduction in coconut growing communities project and work plans	Davao, Philippines	21-23 Aug 2003	80
12th COGENT Steering Committee meeting	Review the progress of COGENT and work plans	Merida, Mexico	10-12 Nov 2003	16
4th Annual CFC-funded project meeting: Coconut Germplasm Utilization and Conservation to Promote Sustainable Coconut Production	Review the progress of the CFC-funded project and work plans	Merida, Mexico	13-17 Nov 2003	21
Poverty Reduction in Coconut Growing Communities (PRCGC): The Final ADB funded Project Meeting	Evaluate the progress and outputs of the project in eight Asia Pacific countries and discuss initial development impact and strategies for upscaling and replication	Ho Chi Minh City, Vietnam	27-30 Sep 2004	24
Final CFC funded Project Meeting	Review the progress of the CFC-funded multilocation coconut hybrid trials and other project components, and discuss the findings on the final evaluation of the project and issues and recommendations	Kuala Lumpur, Malaysia	17-19 Nov 2004	26
13th COGENT Steering Committee Meeting	Review the progress of ongoing and proposed projects and activities of COGENT; status of PROCORD; finalize COGENT's Strategic Plan and refine COGENT's coconut conservation strategy	Kuala Lumpur, Malaysia	22-24 Nov 2004	26
Subtotal for Workshops and Meetings				***863***
GRAND TOTAL				**1045**

Coconut micropropagation

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Introduction

The coconut palm (*Cocos nucifera* L.) is a very important crop providing cash and subsistence to millions of smallholders in 86 countries where about 12 million ha are planted with this palm (Santos 1999). However, most coconut groves require replanting because of loss due either to palm senescence or to diseases such as lethal yellowing in America (Arellano and Oropeza 1995), the lethal diseases in Africa (Eden-Green 1995) and cadang-cadang in Asia, in particular the Philippines (Hanold and Randles 1991). Research on genotype selection for disease resistance or other traits of interest, such as high yield, are being carried out worldwide with positive results (Santos 1999; Zizumbo *et al*. 1999). However, propagation of selected genotypes, or even more conveniently, individuals within these genotypes to satisfy the rapidly growing demands will be very hard to fulfill through natural coconut propagation that occurs only sexually, producing very few seeds per palm within its long life cycle. Therefore, alternative approaches for rapid propagation of improved planting materials must be considered. In this respect, *in vitro* cloning *via* somatic embryogenesis seems to provide a convenient alternative for the future due to its potential for massive propagation. Unfortunately, coconut is a species that responds very poorly to *in vitro* culture, being one of the most recalcitrant species to regenerate *in vitro* (George 1996). This paper summarizes the efforts that have been carried out to develop protocols for the micropropagation of coconut through somatic embryogenesis, presenting the first work carried out during the 20th century and the research advances obtained during the past five years. The paper focuses particularly on research leading to sustained developments such as those related to the use of inflorescence and embryo explants.

Research from the 1970's to the 1990's

Initial developments started with the work of Eeuwens (1976) on improving callus formation and growth by optimizing the mineral composition of the culture media following factorial design experiments.

Testing of the different types of explants followed: young roots of mature palms (Justin 1978), stem and leaf (Pannetier and Buffard-Morel 1982; Gupta *et al*. 1984; Raju *et al*. 1984), embryos (Karunaratne and Periyapperuma 1989) and inflorescences. The first promising results involving somatic embryogenesis were obtained at Wye College (UK) with the first clonal plants produced in 1983 (Branton and Blake 1983) and similar findings were obtained with young leaf explants (Buffard-Morel *et al*. 1992). Low percentage of callus formation and the development of abnormal plants were common occurrences (Branton and Blake 1984; Dublin *et al.* 1991). However, these studies demonstrated that coconut regeneration by somatic embryogenesis was possible.

The use of inflorescence explants

Coconut tissue culturists were initially interested in the use of immature coconut inflorescences as explants because they contain meristematic tissue, which was encouraged to form callus tissue with the addition of an auxin to the culture medium. Immature inflorescences from mature palms could be excised non-destructively from the palms (Rillo 1989). Initial callus formation started at about three months after culture initiation and was observed until about nine months (Hornung and Verdeil 1999). The most commonly used auxin was 2,4-D at varying concentrations, depending on the amount and type of activated charcoal employed. Cytokinins were usually not added to the medium for callus initiation. For instance in Montpellier, the Eeuwens Y3 mineral solution (Eeuwens 1976) was used with the addition of Morel and Wetmore's vitamins (1951), 2.5 g l^{-1} activated charcoal, sucrose at 40 g l^{-1} and agar at 7.5 g l^{-1}, 2,4-D between 13 and 36 mM, due to the variable sensitivity of different palms and the developmental stage of inflorescences to the auxin. Murashige and Skoog medium (1962) with the addition of sucrose, activated charcoal and auxin was also employed for callus production. Callus grown on media with gradually reduced auxin levels (Blake 1990), or by an increase followed by a reduction (Verdeil *et al.* 1992), produced nodular somatic structures that subsequently developed into proembryos and finally into embryos (Verdeil *et al*. 1994). However, the production of good somatic embryos still presented a problem due to the development of fused embryos, fused leafy structures with or without roots and haustorial type tissues (Sugimura and Salvaña 1989; Blake 1990; Verdeil *et al.* 1992).

The main difficulties encountered in coconut regeneration by somatic embryogenesis from inflorescence explants were: intense browning of tissue linked to the oxidation of polyphenols, considerable heterogeneity in tissue response, a strong tendency to produce roots only, low embryogenic potential, poorly developed embryo formation, poor shoot formation and slow growth rate *in vitro*. The first one could be overcome to a great extent by the use of activated charcoal. The others were more difficult to overcome. However, in 1993, several groups (from the University of Hanover, Wye College, L'Institut de Recherche pour le Developpement-Centre de Coopération Internationale en Recherche Agronomique pour le Développement (IRD-CIRAD), Philippine Coconut Authority (PCA) and Centro de Investigación Científica de Yucatán (CICY)) involved in coconut regeneration research gathered together for the first time to start a joint effort to overcome the major difficulties encountered in coconut regeneration. This was made possible through a project funded by the European Commission within the Science and Technology for the Development 3rd Period Programme (STD-3) (ERBTS3*CT940298) that started in January 1993. This project increased the fundamental knowledge on the different aspects of somatic embryogenesis in coconut: morpho-histological development (and infrastructural changes (Verdeil *et al*. 2001); hormone studies (Verdeil *et al*. 1994; Hocher 2003); nutritional studies (Dussert *et al*. 1995a,b; Magnaval *et al.* 1995; 1997); protein phosphorylation during somatic embryogenesis (Islas-Flores *et al*. 2000); and plantlet photosynthesis characterization (Triques *et al.* 1997a,b; Rival *et al*. 1999). These studies increased the understanding of the regeneration process and helped to overcome some of the difficulties encountered in coconut regeneration and improvement of protocols using either inflorescence or plumule explants. Several experimental protocols using inflorescences or plumules are now available. For a more detailed account on coconut regeneration from inflorescence explants, see Hornung and Verdeil (1999). Studies using plumule are described below.

The use of embryo explants

As mentioned above, whole coconut embryos had been used as explants to induce embryogenic calli and somatic embryo formation without success. As an alternative, researchers from Wye College and CICY tested embryo isolated parts: plumules, root poles and cotyledonary tissues. Plumules were the only explants that readily formed embryogenic callus and embryos that developed shoots (Hornung 1995; Oropeza and Chan 1995). Further studies within the EC-STD3 project (reported in Chan *et al*. 1998) were carried out to improve somatic embryogenesis and shoot formation from plumule explants, and ultimately, *ex vitro* plantlet establishment. Plumules from the embryos of nuts harvested 12-14 months after pollination were used and cultured on Y3 medium (Eeuwens 1976) containing activated charcoal and gelrite. Different parameters were tested to optimize callus and somatic embryo formation: concentration of phytohormones, subculture frequency and light conditions. Callus formation required auxin (2,4-D) at an optimum concentration of 0.1 mM 2,4-D. These calli developed meristematic centers and when kept at the same auxin concentration (0.1 mM), the calli developed embryogenic structures. A greater proportion of plumule explants developed into calli bearing embryogenic structures when cultures were kept undisturbed and no subculturing was practised. Histological observations showed that formation of somatic embryos had already started in calli bearing embryogenic structures, but development of embryos occurred when the auxin concentration was reduced by a hundred-fold and cytokinin was added (50 µM 6-BAP), performing better under illumination (12 h photoperiod) than in the dark. Keeping cultures in these conditions and subculturing every three months, allowed embryos to germinate and the resulting shoots eventually developed into plantlets that, after acclimatization, grew successfully under *ex vitro* conditions. Following this protocol, different batches of cultures were tested and the performance was found to be reproducible.

As reported by Chan *et al*. (1998), with plumule explants shorter times were required to obtain somatic embryos (7-9 months) than those previously reported with inflorescence explants (14-20 months, Verdeil *et al*. 1994), and the yields were higher (nearly two-fold for calli and over ten-fold for calli bearing somatic embryos) than those reported with inflorescences (Verdeil *et al*. 1994). Acclimatization has been successful and plantlets did well in open environmental conditions since they continued producing new leaves, sexual organs and fruits. This protocol by Chan *et al*. (1998) reported that 60% of the explants formed initial calli using a local brand charcoal. In Montpellier, by using a different brand (Sigma acid washed charcoal), an improvement in callus induction of nearly 100% was obtained (J.L. Verdeil and V. Hocher, Montpellier, unpublished). Similar results were obtained afterwards at CICY. Therefore, careful selection of charcoal is very important. Clonal plantlets are now produced in most of the participating laboratories within the STD-3 project.

The use of embryo slices as explants and different treatments were evaluated at Queensland University. Polyethyleneglycol and ABA were tested for somatic embryo maturation and had very little or no effect when these chemicals were added separately, but when added simultaneously, they inhibited the growth of non-embryogenic calli and improved the maturation of somatic embryos (Samosir *et al*. 1999). Conditions that increased ethylene concentrations in the above coconut cultures were found to affect callus growth and somatic embryogenesis

(Adkins *et al*. 1999). Accordingly, embryogenic calli were incubated with a number of additives that could reduce ethylene production (aminoethoxyvinylglycine), protect from ethylene (silver thiosulphate) or help combat ethylene-induced stress (polyamines). Coconut somatic embryogenesis was promoted (100%) by the addition of the polyamines putrescine and spermidine to the medium (Adkins *et al*. 1999). Unfortunately, when tested with plumule explants, no promotion of somatic embryo formation was obtained (CICY, unpublished data).

Recent advances

The use of plumule explants

During the past five years, research on the plumule system has continued in order to further improve its performance and different approaches have been tested. The compound 22(S), 23(S)-homobrassinolide was found to increase embryogenic calli and somatic embryo formation (1.5 and 2 fold respectively, compared with the controls) when applied as a pretreatment to plumule explants (Azpeitia *et al*. 2003). Cytokinins have been found to decrease embryogenic callus formation in plumule explants and therefore, the anticytokinin 8-azaadenine was tested. It increased somatic embryo formation 1.5 fold in relation to the control treatment (Azpeitia, 2003). There are other two approaches that resulted in even larger increases of yields: secondary embryogenesis and multiplication of embryogenic calli (CICY, unpublished results). Secondary embryogenesis is based on the use of somatic embryos as explants to produce more embryos. This process can be repeated several times. Therefore, it can be useful to increase the total somatic embryo yield obtained *per* original explant. Embryogenic calli multiplication allows increasing the yield of this type of calli several fold. Unpublished results (CICY) presently show that by combining these two approaches, thousands of embryogenic calli and tens of thousands of somatic embryos can be obtained from one plumule and the amounts depends on the number of multiplying cycles carried out. Furthermore, if these two approaches were combined with the use of 22(S),23(S)-homobrassinolide (Azpeitia *et al*. 2003), yields could be potentially increased even more. This three-approach strategy is being tested in collaboration with COGENT.

Regarding germination and post-germinative development of somatic embryos, studies had been limited by the low yields obtained. Therefore, these studies were approached using the coconut zygotic embryo as a model system. At CICY, this system showed that aerobic respiration was required for embryos to germinate (Pech y Ake *et al*. 2004). Percentage of germination increased from 66% in liquid medium where embryos were submerged to 93% on solid medium where embryos could be placed with their micropylar end facing upwards exposed to the ambient atmosphere of the vial (Pech y Ake *et al*. 2004). This also resulted in increased conversion from 46% to 89% for liquid and solid media, respectively. In addition, the use of gibberelic acid (GA_3) further promoted both germination and conversion into plantlets (Pech y Ake *et al*. 2002). The use of ventilated vessels (with filter paper windows) when compared with sealed vessels, improved the leaf water loss control of plantlets formed from zygotic embryos cultured in these vessels (Talavera *et al*. 2001). *Ex vitro* survival of plantlets was found to be over 90% if proper development was allowed, plantlets should have a minimum of three bifid leaves and three main roots when transferred from *in vitro* conditions to *ex vitro* acclimatization conditions (Pech y Ake 2004). Some of the information obtained using zygotic embryos has been used to help define the optimal germination and post-germination development conditions for somatic embryos. This way, when plantlets derived from somatic embryos were allowed to develop three bifid leaves and three main roots, *ex vitro* survival was over 90% (CICY, unpublished results). Micropropagated palms established in permanent field conditions over four years ago have done well under and some are already bearing fruits. Similar (unpublished) observations have been noted at the Coconut Research Institute in Sri Lanka.

The use of other explants (leaf and inflorescence)

The information obtained on coconut regeneration using plumular explants can be useful to for research on the use of other explants. Research on micropropagation based on inflorescence or leaf explants has not been abandoned and it is one of the main objectives of a project supported by the Australian Centre for International Agricultural Research (ACIAR) involving laboratories at the University of Queensland (Australia), the Research Institute for Coconut and other Palmae (Indonesia), the Philippine Coconut Authority (Philippines), the University of Philippines at Los Baños (Philippines), the Cocoa and Coconut Research Institute (Papua New Guinea) and the Oil Plant Institute (Vietnam). It would be interesting to test the combined use of secondary embryogenesis and embryogenic callus multiplication with inflorescence and leaf explants.

Genetic engineering

In addition, there are new areas of research intended to open new avenues for coconut micropropagation improvement and probably applications. These studies are based on molecular techniques and presented below.

A different approach to increase coconut micropropagation efficiency, not tried before, is to improve the embryogenic capacity of coconut tissues by inserting genes related to this capacity. Hence, the genes and the protocols for their insertion through transformation techniques are needed. Therefore, through a collaborative effort, researchers from Max Planck and Fraunhofer Institutes (Germany) and CICY are attempting to develop transformation protocols for coconut tissues. *Agrobacterium tumefaciens*-mediated transformation and particle gun (Biobalistic) DNA delivery methods have been applied to transform coconut cells using the reporter genes *uidA* that codify for b-glucuronidase (GUS), *gfp* for the green fluorescent protein (GFP) and *rfp* for the red fluorescent protein (RFP) under the control of constitutive promoters such as 35S CaMv and Ubiquitin from Maize. Transient transformation was successfully obtained with both transformation methods and the three reporter genes. However, the use of *uidA* was hampered by the finding of endogenous GUS activity in coconut calli. Stable transformation has been confirmed for *gfp* in *A. tumefaciens*-mediated transformed calli. In addition, the effect of hygromicin and bialaphos has been evaluated as selective agents for transformed cells. The former was shown to be useful, whereas the latter was not. These results have yet to be published.

In vitro manipulation of coconut tissues is limited by the scarce knowledge of their cellular behaviour. A major problem is the difficulty to maintain the meristematic potential of tissues and to further control their capacity for cell division. Therefore, the L'Institut de Recherche pour le Développement - Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement (IRD-CIRAD) started a study on the cell cycle status of *in vitro* coconut cells. Using flow cytometry, most of the cells were found to be in G0/G1 phase (around 90% in nodular calli and shoot meristems), with a low mitotic index (less than 0.5%) (Sandoval *et al*. 2003). These results are in agreement with those obtained by Jesty and Francis (1992) with microdensitometry. Adding aphidicolin (a synchronisator of cell cycle) to the media, around 80% of cells were blocked in G0/G1 and only 20% of meristematic cells were cycling cells (Sandoval *et al*. 2003). Using immature inflorescences and immature leaves, the study showed that flow cytometry methods could be used to rapidly assess the ability of tissues cultured *in vitro* to divide. It appears to be a useful tool for a more effective monitoring of the meristematic potential of tissues cultured *in vitro*, in relation to culture conditions.

The basic components of the cell cycle machinery appear to be conserved in all eukaryotes and particularly those controlling the re-entry of cells in the cell cycle (transition between G0 and G, transition between G1 and S). Screening a coconut shoot meristem cDNA library with heterologous probes (from Maize, *Arabidopsis* and mouse) allowed to isolate cDNA (Cyclin D, cyclin dependant kinase, E2F and retinoblastoma) involved in the retinoblastoma pathway known to control the re-entry of cells into cell cycle and the early cell cycle phases. Among the genes isolated from coconut, those encoding D-type cyclins are of great interest because they are known as favourable candidates for linking the perception of the environment (culture conditions) with cell cycle activity in plants. The study of the accumulation of these cDNA in *in vitro* coconut tissue is now on the way through collaboration between IRD-CIRAD and CICY. It should help to understand the mechanisms controlling the switch from non-cycling cells to cycling cells.

Perspectives and conclusion

The account presented here of the research for the development of efficient coconut micropropagation protocols *via* somatic embryogenesis shows that solid progress has been made and that this has been possible because there has been collaboration among institutions all over the world, particularly in the last ten years. Rapid progress has been made using plumule explants, but there is still work to be done. For instance, there is a need for improving embryo development, mastering germination and post-germination development and continuing genetic stability/integrity testing. Interest in plumule micropropagation started because this could be a useful model system, thus developments obtained with this system should now be tested with other explants such as immature inflorescences and young leaves. From a practical point of view, plumule micropropagation cannot be used for elite plant propagation. However, it can be applied for superior population propagation such as genotypes that are disease resistant. Countries affected by the phytoplasma-associated diseases need urgently at least hundreds of thousands of resistant palms. In the near future, plumule micropropagation could be the way to obtain them. Another application for the plumule system is the multiplication of the Makapuno coconut currently produced by rescuing the embryo of the non-germinating Makapuno nut.

On the other hand, research work on coconut somatic embryogenesis should also incorporate the latest trends in developmental biology as they become available and in particular those concerning the control of embryogenesis and shoot meristem differentiation and functioning. As mentioned above, transformation protocol development is already under way based on plumule micropropagation. Regarding the search for genes, there are recent reports on interesting genes that have been isolated from *Arabidopsis* such as BAYBY BOOM (Boutilier *et al*. 2002) and LEC1 (Lotan *et al*. 1998; Stone *et al*. 2001) encoding transcription factors involved in the conversion from vegetative to embryonic growth. The over-expression of these genes in *Arabidopsis* led to the formation of somatic embryos at the surface of the leaves with a high rate. Such genes are attractive and are promising tools for improving somatic embryogenesis and clonal propagation in coconut.

Finally, it is very important that for future research efforts, collaboration among institutions in different countries is intensified, not only to sustain current progress in coconut micropropagation research, but also to allow it to take place rapidly. To successfully achieve this, the continuing support of Asian Pacific Coconut Community (APCC), Bureau for the development of research on tropical perennial oil crops (BUROTROP) and the International Coconut Genetic Resources Network (COGENT), is absolutely necessary.

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Chapter 6

Major pests and safe movement of germplasm

Coconut lethal yellowing

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Introduction

Lethal yellowing (LY) is a devastating disease that affects more than 38 species of palms (Harrison *et al.* 1999) throughout the Caribbean Region (see McCoy *et al.* 1983) where its effects have been more conspicuous on coconut (*Cocos nucifera* L.) than other palm species because of their abundance. In the last 50 years, LY epidemics in this region have killed millions of palms. The purpose of this paper is to summarize the current status of study and knowledge on LY. For more extensive treatment of particular issues discussed in this section, the reader will be referred to other related publications.

Geographic distribution

Reports of dying coconut palms exhibiting LY-type symptoms date back to 19th century in the Caribbean region (Eden-Green 1997). During the last three decades, epiphytotics of LY in Jamaica and Florida have been characterized by rapid spread and high losses (McCoy *et al*. 1983). LY was first recorded in the Yucatan Peninsula of southern Mexico during 1977 (Oropeza and Zizumbo 1997) and has since spread to Belize (Eden-Green 1997), Honduras (Ashburner *et al.* 1996) and Guatemala (Mejía *et al*. 2004). Similar diseases known as lethal yellowing-type diseases (LYD) have also been described in Africa in Ghana, Togo, Nigeria, Cameroon, Tanzania, Kenya and Mozambique (Eden-Green 1997; Tymon *et al*. 1998; Eden-Green and Mpunami this volume). LY had destroyed millions of palms causing great losses, particularly in Ghana and Tanzania (Schuiling *et al.* 1992).

Symptoms

The first visual symptom of the disease on infected bearing coconut palms is the premature drop of most of the fruit regardless of their developmental stage. The next symptom to appear is the blackening of new inflorescences. This symptom is most apparent as the inflorescence emerges from the spathe. The first affected inflorescences usually show partial necrosis but as the disease progresses, newer inflorescences show more extensive necrosis. Most of the male flowers are dead and no fruit are set on those affected inflorescences. Yellowing of the leaves usually starts after necrosis has developed in more than two inflorescences. The pattern of leaf discoloration due to LY is more rapid than that for normal leaf senescence. The first leaves to turn yellow are the oldest (lower) ones, then yellowing advances upwards; affecting the younger middle and finally the upper leaves. Yellow leaves turn brown, desiccate and die. They remain hanging for a few days before falling. Eventually, the whole crown perishes, leaving a bare trunk or 'telephone pole'.

On the other hand, the syndrome does not always follow the same sequence of events. In some LY affected palms the spear leaf or a midcrown leaf occasionally shows yellowing prematurely (McCoy *et al*. 1983). Sometimes inflorescence necrosis becomes noticeable only after leaf yellowing has appeared as observed in Guatemala (Mejia *et al*. 2004). The estimated time lag from the probable time of initial infection by the pathogen to the appearance of first symptom has been variously reported as follows: in mature bearing palms, 230-450 days (Romney 1972) and 210-450 days (Heinze *et al*. 1972); for young non-bearing palms, at least 240-270 days (Dabek 1974). The time between probable initial infection and death of mature palms has been reported as 3-6 months (Grylls and Hunt 1971) or 4-5 months (McCoy 1973). In addition to these symptoms in above ground parts, roots also show necrosis, which becomes more extensive as the disease progresses (Eden-Green 1979). The growth is also affected by LY. Detailed studies on LY affected coconut palms have revealed physiological and biochemical symptoms (Oropeza *et al*. 1995; Islas-Flores *et al*. 1999; Martínez *et al*. 2000; Maust *et al*. 2003). In general, LY symptoms in other palms are similar but there are some differences (see McCoy *et al*. 1983). Symptoms of coconuts affected by lethal yellowing-like diseases (LYD) in West Africa and Tanzania are similar to those described here for LY in the Americas (Mpunami *et al*. 1999).

Causal agent

Phytoplasmas (previously known as mycoplasma-like organisms or MLO) were first found to be associated with some plant yellows diseases during the 1960s (Doi *et al*. 1967; lshiie *et al*. 1967). These results then sparked the search for phytoplasmas in LY-affected palms. In 1972, three groups independently reported their occurrence in the phloem of coconut palms showing LY symptoms (Beakbane *et al.* 1972; Heinze *et al*. 1972; Plavsic-Banjac *et al*. 1972). A cause-effect relationship between phytoplasmas and LY was supported by the differential response of LY diseased palms to antibiotics. LY palms treated with penicillin showed no beneficial response whereas symptom remission occurred when they were treated with oxytetracycline (Hunt *et al*. 1974; McCoy 1972). Genotypic characterization of coconut-infecting phytoplasmas was possible when pathogen-specific PCR and RFLP-typing or sequence analysis of PCR-amplified rDNA becomes available (Harrison *et al*. 1994a). In this way a Florida strain of the LY agent was assigned as a sole representative member to 16Sr group IV (coconut lethal yellows group), subgroup A (16SrIV-A) (Harrison *et al*. 1994b). Phytoplasmas have also been associated with LYD in West Africa (Dollet *et al*. 1977; Epko and Ojomo 1992) and East Africa (Schuiling *et al.* 1992; Eden-Green and Mpunami, this chapter).

Phytoplasmas associated with Caribbean LY and both West and East African LYD were analyzed using molecular techniques and found to be different but closely genetically related (Harrison *et al*. 1994a). Further studies on phytoplasmas associated with LY-diseased palms in the Americas have shown that there are genetic differences when different locations were compared. Differences were found between the LY phytoplasmas in Florida, México and Jamaica based on the analysis of rDNA (Harrison *et al*. 2002b); and between Cuba and Mexico based on the analysis of non-ribosomal DNA (Llauger *et al*. 2002). In addition, strain diversity within a country has been found in Cuba (Llauger *et al*. 2002), México (Harrison *et al*. 2002a) and Florida (Harrison *et al*. 2002b). Also further studies on the East Africa LYD using rRNA and RFLP analysis showed no differences between the phytoplasmas associated with Tanzania and Kenya LYD, whereas those associated with Mozambique LYD were found to be different and closely related to those from West Africa, Cape St. Paul Wilt (CSPW) in Ghana, and Awka or bronze leaf wilt in Nigeria (Mpunami *et al*. 1999; Eden-Green and Mpunami, this chapter).

Since the 1980's in Florida and Jamaica, unusually high losses of resistant Malayan Dwarfs and MayPan hybrid coconuts have been reported (Howard *et al*. 1987). Comparative analyses of the LY phytoplasma 16S rRNA gene by PCR, RFLP and base sequencing have shown that LY phytoplasma population in Jamaica was homogeneous and varied from the Florida strains (Harrison *et al*. 2002b). The authors conclude that phytoplasma rDNA heterogeneity is probably not correlated with the strain variation in aggressiveness.

Transmission

According to the pattern of spread of LY, it was first hypothesised that it was probably transmitted by flying insects (Johnston 1912). When the causal agent of LY was discovered to be a phytoplasma, the search concentrated on species of *Auchenorrhyncha*, the sub-order of the Homoptera to which most vectors of phytoplasma-associated diseases belong (Tsai 1979). Surveys conducted in LY-affected areas in Jamaica yielded five species of fulgorids (Schuiling 1976; Schuiling *et al*. 1976) and in Florida two fulgorids and one membracid (Howard 1980a; Howard and McCoy 1980; Howard and Mead 1980). The only common species found in coconut palms in both locations was the cixiid *Myndus crudus*. In addition, the apparent rate of spread of LY decreased in areas where *M. crudus* populations were reduced by insecticide treatment (Howard and McCoy 1980) and populations of *M. crudus* were 40 times higher in heavily affected areas than in LY-free areas in Florida (Howard 1980b). As a result of these reports, *M. crudus* has been extensively tested as a vector for LY (Howard 1995). Successful transmission was achieved in Florida using caged palms (*C. nucifera*, *Veitchia merrillii* and *Pritchardia thurstonii*) exposed to large numbers of insects and long incubation times (Howard *et al*. 1982; Howard and Thomas 1980; Howard *et al*. 1984). Every month, approximately 850 wild *M. crudus* captured from landscape palms were introduced into each cage over a 34-month period. Palms in cages where insects were not introduced remained healthy. More recently, detection by PCR of LY-phytoplasma infection on native *M. crudus* in Florida was reported (Harrison and Oropeza 1997). Taken together, these studies indicate the importance of this planthopper as a vector of LY in Florida, but its role as a vector of the disease elsewhere in the Americas remains uncertain. At LY-active sites in southern Mexico, the number of *M. crudus* on coconut palms were found to be several-fold lower than those of many other potential vectors (Escamilla *et al*. 1994).

The possibility of an indirect transmission path, through embryos or asymptomatic alternative host plants, has been considered. DNA of the LY phytoplasma has been detected in embryos from fruits of diseased Atlantic Tall coconut palms by DNA hybridization (Cordova 1994), and PCR analysis (Cordova *et al*. 2003). Phytoplasma distribution in sectioned tissues from PCR-positive embryos determined by *in situ* PCR and digoxigenin-11-deoxy-UTP (Dig) labelling of amplification products was limited to areas corresponding to the plumule and cells ensheathing it (Cordova *et al*. 2003). By comparison, similarly treated embryo sections derived from fruits of a symptomless Atlantic Tall coconut palm were consistently devoid of any label. Occurrence of LY phytoplasma DNA has been shown most recently in embryos from fruits at different stages of development (Chumba 2003). Presence of phytoplasma DNA in coconut embryo tissues suggests a potential for seed transmission which remains to be demonstrated. The palms *Thrinax radiata* and *Cocothrinax redii* that have been listed as not susceptible by McCoy *et al*. (1983) and were not listed as susceptible by Harrison *et al*. (1999) are very common on the coastal areas of Yucatan where most of the coconut palms have been killed by LY. Analysis by PCR with LY-specific, non-ribosomal primers (Harrison *et al*. 1994a) of symptomless palms of these species resulted in positive detection of the LY phytoplasma in most of them (CICY, 2004, Mexico, unpublished results). Therefore, these palms could serve as potential reservoirs of LY phytoplasma for acquisition by vector insects.

Diagnosis and detection

Visual symptom progression on palm hosts allows for a tentative diagnosis of LY disease. However, confirmation of disease requires detection of the LY phytoplasmas in host tissues. This can be achieved directly by their observation in preparations of diseased tissue using transmission electron microscopy or indirectly by observation of their DNA, using DAPI staining and epifluorescence microscopy. These techniques are not specific since they cannot differentiate one phytoplasma from another. However, diagnosis can also be supported by the differential responses of diseased palms to the antibiotics penicillin and oxytetracyline, which provide evidence of a cause-effect relationship of phytoplasma infection and LY. Recent progress in the development of molecular diagnostic assays based upon DNA probe hybridisation and PCR has significantly enhanced detection of phytoplasmas, especially in woody perennial plant hosts such as coconut palm which usually contain low pathogen concentrations. These techniques are also highly sensitive and specific, and well suited for assessing large numbers of samples. LY-specific DNA probes were developed by Harrison *et al*. (1992) and have been used for detection and identification of the LY phytoplasma in symptomatic coconut and several other species (Harrison *et al.* 1992; Harrison *et al.* 1994b; Escamilla *et al*. 1995). PCR assays have been developed for the amplification of rDNA and non-ribosomal DNA for the detection of the LY phytoplasmas (Harrison *et al*. 1994a, b). Assays can be coupled with RFLP-typing or sequence analysis of PCR-amplified rDNA for genotypic characterization of LY phytoplasmas as detailed above. These techniques, particularly PCR, have been used for studies on the plant-pathogen-vector-environment relations also. One such study investigated the time-space distribution of phytoplasmas throughout the coconut palm. The results confirmed that they are detectable in all growing parts except mature leaves, which are actively exporting photosynthates (Cordova 2000). These results have helped determine what parts of palms are most useful for sampling for diagnostic purposes. The trunk was found to support detectable phytoplasma concentrations even before symptoms appear. Currently, this is the most common sampled tissue because of its convenience (Harrison *et al*. 1999).

Spread

Two types of spread of LY have been reported in Jamaica and Florida (see McCoy *et al*. 1983). One involves a local centre of infection that appears in one or two palms only, followed by new cases appearing at random around the initial centre, thereby extending local spread. The second type is a jump spread followed by local spread. The jump distance varies from a few to 70 km or more (Carter, 1964). McCoy (1976) noted that the rate of long distance spread of LY in Jamaica appeared to be slower than in Florida. It took more than 60 years to cover the distance between the west and east end of the island, whereas in Florida it jumped from Miami to Palm Beach and Naples and to Nassau in the Bahamas within three years. McCoy (1976) considered that the mountainous terrain of Jamaica probably contributed to the slower rate of long distance dispersal whereas Florida has no barriers to air-borne dispersal. In Mexico, LY spread about 900 km westward from the Cozumel-Cancun area, where it was first observed in 1979, to the Campeche-Tabasco border in 15 years (Escamilla *et al*. 1995). The account by McCoy (1976) of a survey of LY spread in Dade County, where it first appeared in mainland Florida in late 1971, illustrates patterns of spread for a locality. Of the estimated original coconut palm population of 350 000, 0.015% of the palms were already diseased when the survey began; 0.6% by the end of 1972; nearly 6% by autumn of 1973; 50% by the end of 1974; and 75% by the end of 1975. Regarding LY tree-to-tree spread, in Dade County in the first eight months after arrival of the disease when only a small portion of the area was affected, each infected palm served to inoculate an average of 4.6 new palms according to McCoy *et al*. (1983). Two years later, when the logarithmic stage of spread was well underway, each infected palm served to infect 9.3 new palms. The author considered this increase as a result of the greater availability of inoculum in relation to the remaining uninfected palms. The type of locality was also found to affect the rate of the spread of LY. The highest rate was found in inland groups of palms receiving regular irrigation and fertilization; the lowest rate occurred adjacent to the ocean, even with high maintenance; and intermediate rates in inland sites receiving minimal maintenance (McCoy 1976).

Studies carried out in Yucatan determined the LY spread gradients within a coconut grove and between coconut groves, as well as the palm to palm spread pattern. It was found that within a grove as the LY incidence or proportion of infected palms in an outbreak grows, the greater is the distance the disease spreads from the outbreak; and that it does so as a symmetrical radial gradient (Gongora *et al*. 2001). For longer distances, dispersal between groves gradients were asymmetrical and depended on the prevailing wind direction. Since the prevailing direction is east-west in this part of Mexico, LY spread was greater to the west than to the east (Mora and Escamilla 2001). Regarding the pattern of palm to palm spread, when LY was studied by following visual symptoms, disease was randomly distributed within the first 10 months, started to form aggregates after 12 months and eventually it was found to be uniformly distributed throughout the study area (Perez *et al.* 2000). However, use of PCR detection shows aggregate formation when, according to symptoms, distribution was random (Canché 2002). Moreover, spatial autocorrelation analysis based on visual symptoms indicated that a diseased palm can infect adjacent palms situated as far as eight lags (a lag is the separation between two palms, in this case 8 m) (Escamilla and Mora 2003). This was also confirmed by PCR analysis (J. Escamilla 2004, personal communication). Studies on CSPW disease in coconut plantations in Ghana have also revealed that in almost every case the disease first occurs randomly on isolated palms, spreading to the entire plot in patches and then little by little to all the coconut plantations in a given region (Dery and Philippe 1997). It can also spread in jumps of varying distances (Dery and Philippe 1997).

Control methods

Despite decades of research, a cure for LY is not yet available, but measures may be taken to attempt to reduce its rate of spread. Current and potential methods include quarantine, chemotherapy, vector control, sanitation and the use of resistant varieties. Control of the vector has been approached using insecticides. In tests carried out by Howard and McCoy (1980), and Reinert (1977), *M. crudus* populations were reduced by insecticide treatment, but not sufficiently to be recommended for practical purposes (McCoy *et al*. 1983). Due to the phytoplasma nature of the causal agent of LY, antibiotics were tested in Florida (see McCoy *et al.* 1983) and Jamaica (Hunt *et al*. 1974). It was found that tetracycline group antibiotics suppressed symptom development if applied before expression of systemic foliar yellowing. Chemotherapy has been successfully used for treating host palms used for ornamental purposes, but is not feasible for commercial plantations because of its high cost and perceived health risks. According to McCoy *et al*. (1983), eradication of diseased palms could be useful in slowing the spread of LY if practised in the early stages of the outbreak. He noted that a major drawback of this practise is that LY has a long latent period. However, according to the current epidemiological knowledge for LY as commented in the previous section, if eradication is rigorously practised very early when an outbreak starts, its contribution to delaying disease spread could be substantial. On the other hand, although LY spreads rapidly in any locality where it has become established and jumps large distances to establish new infection sites, quarantine of infested areas could retard disease spread since the greatest majority of new cases occur within 100 meters of any established case of disease (McCoy *et al*. 1976).

Nevertheless, replanting with resistant palms has proven to be the most efficient way to deal with LY. Trials evaluating LY resistance have been performed in Jamaica (Been 1991). Resistance was found in some ecotypes, including the Malayan Dwarf varieties, of which the yellow variety (MYD) was subsequently used as a parent for F_1 hybrid production. Hybrids produced with MYD as one of the parents had a level of resistance sufficient to be used for commercial planting. Based on these findings, replanting in Jamaica using MYD and the Maypan hybrids (MYD x Panama Tall) has proved successful (Been and Myrie, this chapter). From a commercial perspective, Maypan offers several advantages: it is resistant to LY, precocious and highly productive (Been 1991). Unfortunately unusually high losses of resistant MYD and Maypan hybrid coconuts have been reported (Howard *et al.* 1987) and recent outbreaks in northern Jamaica have recently killed up to two thirds of MYD and Maypans (see Harrison *et al*. 2002a).

After LY arrived in Mexico, a search for resistant germplasm began. CICY collected 18 coconut populations mostly from the Pacific Coastal areas of Mexico in 1989, when LY was not present there. Resistance trials were established in Yucatan in an LY affected area. These populations were grouped into five ecotypes: Atlantic Tall, MYD, Pacific Tall 1, Pacific Tall 2, and Pacific Tall 3. After more than ten years of testing, new LY highly resistant germplasm have been identified, namely Pacific Tall 1 and Pacific Tall 2 (Zizumbo *et al*. 1999). They are also surviving in their original planting locations (D Zizumbo 2004, personal communication) co-existing with different LY phytoplasma strains identified there (see Harrison *et al*. 2002a). They are currently being used for improvement and replanting programmes in Mexico and Honduras. Testing of these ecotypes and Tall x Tall hybrids produced with them started in Jamaica three years ago to determine if they can survive the ongoing resurgence of LY outbreaks there. Future searches for additional sources of resistance could be facilitated by using microsatellite markers (Baudouin and Lebrun 2002).

Conclusion

Despite decades of efforts to deal with LY and LYD, these diseases are still spreading and killing palms in the Americas and Africa. In the past 50 years, LY has moved to Mexico, Belize, Guatemala and Honduras. New outbreaks in Jamaica, in particular, are very worrisome because resistant MYD and Maypans varieties are dying in unusually high proportions. The reasons for this newest development are as yet unknown. However, sustained research efforts on these diseases have been steadily generating novel and important information. PCR-based detection methodologies have provided more sensitive, and specific diagnostic capabilities that are well suited for assessing large numbers of samples than the previous ones. They have enabled studies toward a better understanding of the pathogen and its interactions with host palms and should facilitate studies focusing on vectors. We know now that there is strain diversity among LY phytoplasma populations and several strains have been identified and classified. From a practical stand point, PCR and improved sampling protocols have allowed more efficient monitoring of disease spread within countries and local regions. This timely information has been very important for updating quarantine programmes in affected countries. Epidemiological studies indicate that prompt eradication has potential to limit disease spread and molecular diagnostics are setting the bases for its improvement. Once again, resistant germplasm is a priority, and fortunately, new sources of resistant coconuts have been recognized in the Pacific coastal areas of Mexico. These materials are already being exploited in Mexico and Honduras and hopefully, trials in Jamaica to determine their response to the current outbreaks there will prove successful.

For the future, it is necessary to extend the quest for resistant coconut genotypes to encompass the entire Pacific coast of Central America. We need a better understanding of the pathogen and to clarify the vector identity to elucidate vector-host relationships. However, in order to achieve any further advancement, it will be very important to use new techniques as they become available, for example, the microsatellite technology for the characterization of coconut germplasm. Other new avenues have already been opened. A study with the goal of sequencing the LY phytoplasma genome is underway and should, in the near future, yield invaluable information on the molecular basis of phytoplasma-palm-vector interactions and pathogen virulence mechanisms. Coupled with transformation techniques already under development, collectively, these efforts should provide a means for molecular improvement of coconut.

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Status of coconut lethal yellowing in Jamaica

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Introduction

Lethal yellowing disease (LY), probably the most devastating of diseases which affect the coconut palm (*Cocos nucifera* L.), is one of the greatest threats to coconut cultivation not only in the Caribbean and the Americas but worldwide. It is associated with phytoplasmas, and *Myndus crudus Van Duzee* is a probable vector (Beakbane *et al*. 1972; Plavsic-Banjac *et al*. 1972; Howard *et al*. 1983).

Despite the considerable research, which has been carried out on the disease, no permanent cure has yet been found.

History of LY in Jamaica

LY was first reported from the Cayman Islands in 1834. In Jamaica, the disease was first observed in the south western section of the island in 1884 (Fawcett 1891). Nevertheless, it is possible that in 1872 it, or a similar disease, wiped out coconut palms along a forty-mile coastal strip in the south west. The disease continued to be endemic in the western region for decades and by 1952 had spread over the western half of the island (Martyn 1949; Nutman and Roberts 1955). The greatest damage was done in the coconut belt bordering the north west coast but the disease was not found a few miles inland, but there were not many plantations inland in that area.

In 1961, LY appeared suddenly in the north eastern section of the island, over 100 km from the nearest case in the west, and subsequently spread rapidly throughout the main coconut growing region destroying existing coconut plantations. Of the estimated six million coconut palms growing in Jamaica in 1961, 90% was lost to LY by 1981.

By 1981 when LY was active island wide, mortality levels of the Malayan Dwarf and Maypan were 5% and 10%, respectively (Been 1981). During the early 1980s, LY was largely confined to surviving Jamaica Tall palms and materials of uncertain origin. About the mid-1980s, at certain coastal locations in the north western region there were reports of higher than anticipated levels of LY mortality among Malayan Dwarf and Maypan populations. At some places mortalities were as high as 40%.

Following a disastrous hurricane in 1988 the incidence of LY increased significantly and new outbreaks were reported in eastern Jamaica. At various points along the coastal areas of the northern region mortality levels among stands of the Malayan Dwarf and Maypan were found to be consistently higher than those observed in 1981. The trend continued during the 1990s and in certain places the disease began to move inland.

The mortality level varies; in the western section it is generally lower than in the east where a field of 747 Malayan Dwarfs died over the period 1993 to 1999, and a population of 792 Maypan hybrids between 1997 and 2000 (Myrie 2002). In the western section, mortality rate is generally slower, about 2% per annum, than in the east, which is about 14-25% per annum (Myrie 2002).

The LY disease of the 1990s had the usual characteristics of the LY of the 1970s; however, there was an interesting difference in that it attacked non-bearing palms with greater frequency.

At present, the disease is largely confined to the coastal areas and its incidence on most of the inland farms is low. The main germplasm collections having survived LY of the 1960s and 1970s are still to be exposed fully to the 'new' LY. However, to date no variety currently being cultivated in the areas where the disease is active has shown any sign of possessing a high or any level of resistance. At two experimental sites, the following F_1 hybrids – Indian Green Dwarf x Panama Tall, Ceylon Green Dwarf x Panama Tall, Ceylon Yellow Dwarf x Panama Tall and Maypan – have all failed to stand up to the disease (Wallace 2002). Indian Green and Ceylon Yellow and Green Dwarfs had shown high levels of LY resistance, almost as high as that of the Malayan Dwarf.

It has been estimated that over the past decade about 800 000 palms have been destroyed by LY in the eastern section of the island and the disease continues its advance.

The coconut is not indigenous to Jamaica and when LY first appeared in the 18th century, the Jamaica Tall was the principal variety being cultivated – a situation, which remained unchanged until the 1970's. Unfortunately, it is highly susceptible to the disease. There is no record of LY affecting other palm species in Jamaica during the 18th century.

Searching for the cause

From the late 1880s, attempts were made to determine the cause of LY and ways of controlling its spread. Considerable research was done over the years by many workers, especially in Jamaica and Florida (Romney 1983; McKoy *et al*. 1983). Failure to obtain evidence that fungi, bacteria, nematodes, soil and other environmental factors were the cause led to the conclusion that LY had a viral aetiology (Bruner and Boucle 1943; Nutman and Roberts 1955). This led to attempts to transmit the disease to healthy palms and the search for an insect vector (Carter 1966; Grylls *et al*. 1968; Heinze 1971).

The discovery of phytoplasmas on LY-infected coconut palms in 1971 changed the direction of the research effort. The search for an insect vector was narrowed down to leaf hoppers and, in Florida, *Myndus crudus Van Duzee* was found to be a vector of the phytoplasma associated with LY (Howard *et al.* 1983).

Living with LY before 1961

Early attempts were made to control the spread of the disease by isolation and elimination of outbreaks. Felling and burning of palms were carried out, but these failed to halt the spread of the disease. Government legislation was enacted to control the movement of plant parts and soil eastwards into the disease-free area, but the boundary was an open one, which was impossible to maintain in accordance with any proposed quarantine requirements.

In disease affected areas, replanting was done with whatever planting material was available. In the early part of the century, the north western coastal strip was replanted at least four times with remnants of the fourth replanting having all but died out by 1954 (Nutman and Roberts 1955). Many growers in the eastern part of the island believed that the Jamaica Tall palms they were cultivating were of a different, resistant type.

Living with LY after 1961

The sudden appearance of LY in the main coconut-growing area in the eastern end of Jamaica in 1961 posed an enormous problem for the Coconut Industry Board (CIB), which had been established in 1945 to promote the interests and efficiency of the coconut industry. Before 1945, research and extension for coconuts were done by the Ministry of Agriculture.

It was realized from the outset that the additional costs of research on LY could not be provided by the CIB and, therefore, external assistance was sought and obtained.

Initially, the United States Agency for International Development (USAID) provided collaborating scientists and later the Food and Agriculture Organization (FAO) of the United Nations supported the research effort. Researchers from Australia, Germany and the Netherlands came to Jamaica for extended periods to work with local staff. At about the time that the FAO project was about to end, the United Kingdom (UK) government through its Overseas Development Administration (ODA) supplied a research team and an electron microscope. Researchers from the University of Florida also worked in Jamaica. Research institutions in the UK and United States of America (USA) were involved in the research effort. The Ministry of Agriculture, University of the West

Indies, Institut de Recherches pour Huiles et Oléagineux (IRHO) and Unilever also cooperated with the CIB.

External funding ceased in the early 1980s but before then, considerable work was done and valuable information obtained. Research on the nature of LY was done largely by visiting scientists, while local staff concentrated mainly on plant improvement and management. The original local research programme had to be modified with emphasis being placed on selection and breeding for disease resistance, and the management methods needed were those suited to resistant varieties.

A programme to monitor the disease was put in place to determine which palms were dying from LY as opposed to other causes. It also provided useful information on varietal resistance and data for replanting programmes.

Felling of affected palms to check the spread of the disease was as ineffective as it had been in the west, and was abandoned. Pesticides were used in an attempt to control new outbreaks before they could spread, but without success. The concept was to treat all palms around a single diseased palm with insecticides so that the vectors would be killed before they could pick up the phytoplasmas from infected palms that had no symptoms.

Once phytoplasmas had been found in diseased palms, it was realized that tetracycline could be used to suppress LY symptoms and keep palms alive for years, but it was not a permanent cure. Chemotherapy was rejected as a means of controlling the spread of LY in Jamaica because of the health hazard and high costs.

In 1961, the vast majority of the commercially-grown palms in Jamaica consisted of the LY-susceptible Jamaica Tall variety but there were also populations of the Malayan Dwarf and Panama Tall which were grown from seednuts imported after hurricanes destroyed coconut stands earlier in the century.

Realization by the mid-1950s that the Malayan Dwarf palms (all three colour forms) were highly resistant to LY led to the search for other resistant material and the introduction and establishment of a large germplasm collection in Jamaica by the CIB during the 1960s.

These introductions were screened for resistance in field trials. When it became obvious that none of the introductions was more resistant than the Malayan Dwarf, a hybridization programme was started in an attempt to combine in the F_1 the high disease resistance of the Dwarf with the large fruit size and hardiness of the Talls. One of the early crosses (Malayan Dwarf x Panama Tall or Maypan) was found to be productive and resistant, and a system was devised to produce it commercially.

Once the resistance of the Malayan Dwarf had been sufficiently proven, thousands of mother palms were selected for regular seed production. From then on, even in areas not yet attacked by the disease, the Malayan Dwarf was planted instead of the Jamaica Tall.

By 1974, the Maypan had shown sufficient disease resistance and productivity and was released to growers. In an attempt to speed up replanting, the Advisory Section of the CIB was expanded and seed gardens and nurseries established at numerous sites for the effective and efficient distribution of seedlings. In addition, assistance programmes under which growers received free planting material and fertilizer, and cash grants to help with weed control were instituted. As a consequence of these efforts by the CIB, three million resistant seedlings were distributed by 1979 and by 1988, ten million.

Current status of LY and future prospects

The coconut industry has remained viable through the use of varieties with good disease resistance, but it now appears as if this resistance is being overcome.

The main varieties being cultivated – the Maypan F_1 hybrid and the Malayan Dwarf – are showing little resistance to the resurgent LY, and preliminary observations suggest that other locally developed F_1 hybrids and germplasm recently introduced may not be any better.

It is possible that the causative agent of LY has mutated and/or exceptional environmental conditions may be combining to produce situations favourable to the development and spread of the disease.

The CIB realizes that if the local industry is to remain viable and survive, it is imperative that some ways be found to cope with LY.

In response to the resurgence of LY, assistance was sought from many sources including the Common Fund for Commodities (CFC) and FAO. As a consequence, the CFC funded an 'Expert Consultation on Sustainable Coconut Production through Control of Lethal Yellowing' which was held in Jamaica in 2002, and a project entitled 'Sustainable Coconut Production through Control of Lethal Yellowing Disease' was submitted to the CFC and, following its approval, is now being implemented.

The current activities of the CIB related to LY include:

- Monitoring the disease and studying its epidemiology;
- Characterization of the pathogen and host;
- Identification and characterization of insect vector(s) of LY (in collaboration with the University of the West Indies);
- Screening of existing local populations and new F_1 hybrids, and introduced germplasm for LY resistance; and
- Encouraging the planting of coconut palms in areas not currently affected by LY and intensify intercropping.

At present, the CIB does not have any variety which has proven resistance to the LY of the 1990s, but seedlings of the Maypan and Malayan Dwarf are being made available to farmers free or at subsidized prices. Farmers are given regular updates of the disease situation and told that it might not be advisable to replant until disease activity in their areas has abated.

The answer to LY may well lie in the realm of genetic engineering but, in the meantime, conventional methods of plant breeding will have to be used and every effort made to develop an integrated approach to disease control.

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Indexing and pathogen characterization

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Introduction

Safe movement means movement of coconut germplasm without introducing pests (taken here to include diseases), or at least those pests for which there are perceived risks of harmful or undesirable effects following introduction to a previously unaffected region. This section is concerned primarily with pests of quarantine significance (mostly diseases) that are likely to be spread through planting materials derived directly from parent plants which appear to be healthy to the naked eye but might be infected without showing symptoms. These include several intractable and lethal diseases which are difficult to diagnose or characterize; some of unknown or uncertain aetiology. Detection of the causal agents may require the use of laboratory diagnostic tests or indexing either of the planting material itself or of the parent population from which it is derived. As yet, most lethal diseases have a limited geographic distribution although different strains of the pathogen may be present both within and between regions that are considered to be affected by the same disease. This emphasises the need for careful and responsible attention to phytosanitary issues when moving germplasm and, in particular, for robust and sensitive diagnostic techniques and accurate characterization procedures to distinguish between strains that could be spread in planting materials.

Pests of concern to the safe movement of coconut germplasm

Pests of quarantine concern are reviewed in the FAO/IBPGR technical guidelines for the safe movement of coconut germplasm (Frison and Putter 1993; Frison *et al*. 1997). Adherence to the general phytosanitary principles recommended for the movement of coconut germplasm as seednuts, embryo cultures and pollen eliminates the risk of spread of most arthropod pests and fungal pathogens, although alternatives to fumigation of seednuts by methyl bromide will have to be found as the use of this chemical is phased out under the Montreal Protocol on substances that deplete the ozone layer. This section summarises the more sophisticated diagnostic or characterization techniques that are required to implement the guidelines for diseases associated with phytoplasmas, viroids, viruses, protozoa, nematodes and draws attention to the risks posed by diseases of yet unknown cause.

Phytoplasma diseases

Phytoplasmas (formerly known as mycoplasma-like organisms, MLO) have been associated with diseases of coconut and certain other palms in most of the continental coconut growing regions. Lethal yellowing (LY) was originally recognised over 100 years ago in the northern Caribbean (Jamaica, Cayman, Cuba, Hispaniola and southern Bahamas) but is now present in southeastern USA (Florida, Texas), Mexico, Belize and Honduras. Similar lethal yellowing-like diseases (LYD) have been reported from Africa since the early 1900s where they have become known by various local names: Cape St Paul wilt disease (CSPWD) in Ghana, Kaincopé disease in Togo, Awka or bronze leaf wilt in Nigeria, Kribi disease in Cameroon, lethal disease in Tanzania, Kenya and Mozambique (Eden-Green 1997a). All of these show symptoms similar to LY.

In Asia, phytoplasmas have recently been detected in coconut palms affected by lethal diseases, but not in symptomless palms, particularly in Indonesia (Kalimantan wilt in Central Kalimantan, Natuna wilt in Natuna Islands) (Allorerung *et al*. 1999). Some of the symptoms of these conditions differ from those of LY and LYD but resemble those reported elsewhere in Southeast Asia (Sumatra, Malaysia, Socorro wilt in the Philippines). All of these diseases may prove to have similar phytoplasma aetiology (Eden-Green 1997b). In India, electron microscope observations showed of an association of phytoplasmas with coconut root wilt and Tatipaka wilt diseases, and application of tetracycline antibiotics reportedly caused remission of root (wilt) symptoms (Solomon 1997). However, attempts to confirm the presence of phytoplasmas by PCR have not been successful (Harrison and Jones 2003). In West Africa, phytoplasmas have also been implicated in a blast disease of seedling coconut palms that appears to have no association with LYD (Julia 1979).

Earlier diagnoses were based on electron microscope examination of ultrathin sections, supported by observation of remission of symptoms following application of tetracycline antibiotics. These remain as valuable diagnostic tools but molecular methods, based on PCR amplification of DNA with specific primers and characterization of the products, now provide more practical and sensitive means to detect the pathogen. These techniques have revealed a considerable genetic diversity of putative strains of phytoplasmas that has not yet been related to phenotypic characteristics. However, differences in the field susceptibility of coconut varieties to diseases in different regions have been known for some time, suggesting that these genetic differences may be of quarantine significance.

Indexing and pathogen characterization

Until molecular properties can be associated with phenotypic characteristics such as pathogenicity and host range, observations on symptoms, varietal susceptibility and alternative hosts remain important characteristic features and should not be neglected. However, molecular techniques are the methods of choice for sensitive and specific diagnosis and characterization of phytoplasmas. DNA probes have been developed for Caribbean LY and East African LYD phytoplasmas (Harrison *et al.* 1992; Mpunami *et al.* 1997; Mpunami 1997) and can be used in dot blot hybridization tests to detect phytoplasmas in palm tissues. However, these probes suffer from problems of background hybridization to healthy coconut DNA and have been generally superseded by DNA amplification by polymerase chain reaction (PCR) using oligonucleotide primers (Harrison *et al.* 1994a). Specific primers for the detection of LYD phytoplasmas in East Africa were subsequently developed (Rohde *et al.* 1993). As well, *Mollicute*-specific PCR primers were optimized for amplification of LYD DNA from palms infected by East and West African coconut yellowing diseases (Tymon *et al*. 1997; Mpunami *et al.* 1997). The PCR technique has been used to confirm the phytoplasma aetiology of the LYD diseases in Kenya and Mozambique, for routine detection of incubating infections in palm tissue, in coconut embryos and in insects suspected to be potential vectors of the disease in Tanzania (Mpunami 1997; Mpunami *et al*. 2000;). Similarly, LYD phytoplasma DNA has been detected in the embryos of nuts harvested from diseased palms, but carry over to palm sprouts has not been established.

Higher specificity for detection of the LYD diseases in East and West Africa has been achieved by the use of primers based on the nucleotide sequence of the intergenic region between 16S and 23S rRNA genes for each LYD isolate (Tymon and Jones 1997). Specific detection of the West African LYD has since been routinely carried out by using specific primers in PCR reactions (Quaicoe *et al.* 2000). Similarly, specific primers for the LYD phytoplasmas in East Africa have been useful for detection and for differentiation of LYD strains within the region. By these means, it has been shown that the phytoplasma strains responsible for disease in Kenya and Tanzania are identical, but the isolate from Mozambique is different, and is more closely related to the isolates from West Africa (Mpunami 1997; Mpunami *et al.* 1999).

Procedures that enhance the PCR technique have also offered increased specificity and sensitivity for detection of the pathogen. For example the nested PCR technique (Haqqi *et al*. 1988; Steffan and Atlas 1991) utilizing Mollicute-specific primers (Deng and Hiruki 1991; Namba *et al*. 1993) in the first reaction, and phytoplasma specific primers

(Gundersen and Lee 1996) in the second reaction is used for routine detection of the LYD phytoplasma in Tanzania. The PCR assays have been particularly useful for determining the genetic relationships between the LYD isolates from East and West Africa, and their relationship to the LY phytoplasma. By analyzing the restriction fragment polymorphisms of amplified PCR products, it has been shown that the isolates from West Africa are similar but genetically different from those causing disease in East Africa and the Caribbean region (Harrison *et al.* 1994b; Tymon *et al*. 1998). The technique has also demonstrated that the LYD strains in Ghana and Nigeria are genetically identical, but different though similar to the LYD strains in East Africa (Tymon *et al.* 1997). The Caribbean diseases appear to exist as a group of closely related strains that are most closely related to a phytoplasma associated with declines of coconut and *Carludovica palmata* in southern Mexico (Cordova *et al*. 2000) and *Phoenix canariensis* in Texas (Harrison *et al*. 2002). The relationship of phytoplasmas recently associated with Porroca disease in southern Panama and northern Colombia (http://review.ucsc.edu/winter-03/panamas.html) has not yet been reported.

The significance of these techniques lies in the ability to determine for what materials, and between which countries there are potential quarantine risks and, potentially, to assess whether host resistance observed in one region is likely transferable to another. Sensitive detection procedures also provide a means to monitor the persistence of the presumed pathogen in seedlings derived from diseased palms to resolve the question of whether or not there is a risk of spread of the disease in seednuts. As knowledge on the variability and distribution of LYD phytoplasma strains improves, it should become possible to base quarantine decisions on the local strains present and to facilitate safe movement of germplasm between regions affected by the same strains, avoiding the need for decentralised diagnostic facilities within importing countries. However, recent experience in Jamaica suggests that new strains of the pathogen can arise that are able to invade previously-resistant hosts, and molecular characterization tests do not yet allow strains to be differentiated on the basis of host specificity.

Problems and research needs

Lethal yellowing type diseases are recognized as the biggest threat to coconut production. Disease resistance is the only feasible method of control and has been used with great effect in the Caribbean region although there is evidence that this has now broken down in Jamaica (CFC 2002). Although specific pathogen characterization techniques have been developed, the mode of transmission has not been established in several regions and the suspected insect vectors have not been confirmed. One of the biggest uncertainties is whether seed transmission is possible. Available (and largely circumstantial) evidence suggests that if this can occur at all then it is extremely rare, and provided the recommended guidelines are observed then any risk should be eliminated. However, recent reports of persistence of phytoplasmas, or at least phytoplasma DNA, in coconut embryos collected from diseased palms make this an important topic for research.

Virus disease: Vanuatu wilt or coconut foliar decay

Coconut foliar decay (CFD) affects introduced coconut palm cultivars in Vanuatu. It is caused by a single stranded DNA (ssDNA) virus (Randles *et al*. 1986, 1987) transmitted by the plant hopper *Myndus taffini* (Homoptera: Cixiidae; Julia 1982). Affected palms typically show a normal apex, several yellowish fronds, then several, young dead fronds hanging through green older fronds. The trunk generally narrows and may thicken again if remission occurs, as happens in tolerant palm varieties. Susceptible cultivars die between one and two years after symptoms appear. The Malayan Red Dwarf (MRD) is highly susceptible to CFD but the local Vanuatu Tall is highly tolerant (*i.e.* can be infected without showing symptoms) and its progenies show only mild symptoms. The use of symptoms alone for CFD diagnosis is thus unreliable (Calvez *et al.* 1980).

Indexing

The MRD can be used as an indicator plant as it is highly susceptible to CFD and shows characteristic symptoms. However, detection and diagnosis are usually based on detection and partial characterization of viral ssDNA by gel electrophoresis, cDNA probes or DNA amplification and sequencing. The CFD virus ssDNA has characteristically low electrophoretic mobility in 5% polyacrylamide gels (PAGE) (Randles *et al*. 1986) and migrates as a single band in denaturing polyacrylamide gels, but generally as two bands in non-denaturing gels (Randles *et al*. 1987). A two-dimensional PAGE technique has been used to show that the DNA molecules are circular in nature (Randles *et al*. 1987). PAGE analysis provides presumptive diagnosis but confirmation requires DNA hybridization and/or sequencing.

Pathogen characterization

Purification by isopycnic density gradient centrifugation [30%–60% Nycodenz (Nyegaard, Oslo) gradient] results in the co-purification of CFD-associated DNA (CFDV DNA) and unusual, 20 nm, icosahedral particles (Nycodenz density range 1.27–1.30 g ml^{-1}), which are considered to be coconut foliar decay virus (CFDV) particles (Randles and Hanold 1989). Both CFD DNA and the particles occur in very low amounts in diseased coconut palms. Although the DNA sedimentation coefficient is only 12S to 15S, the virus has been placed in the geminivirus group. Geminiviruses have ssDNA ($s_{20,w}$ = 16S at pH 7.0) and contain either 1 or 2 circular ssDNA molecules of approximately 7–8 × 10^5 daltons mol. wt, comprising about 2700 nucleotides (Harrison 1985). Examination of purified extracts from CFD-infected palms by transmission electron microscopy shows circular molecules with mean molecular weight of approx. 4.3 × 10^5 daltons.

A molecular hybridization assay has been developed using a P^{32}-labelled cDNA probe synthesized from a 1203 bp DNA fragment, amplified by PCR from circular, single-stranded, 1291-nucleotide CFDV DNA (Rohde *et al.* 1990; Randles *et al.* 1992). The high specificity and sensitivity of this assay allows CFDV DNA to be detected reliably, despite its low concentration in coconut tissue. A non-radioactive probe using digoxygenin (DIG)- labelled complementary RNA (cRNA) has also been developed as an alternative detection method (Hanold and Randles 1997). Hybridization assays have been useful in studying the distribution of CFDV DNA in palm tissue in order to establish priority areas for disease diagnosis, for localization of the virus in phloem tissues (Randles *et al.* 1992; Hanold and Randles 1997), and for detection of the virus in the vector.

To obtain sequence data on CFDV DNA, a single-stranded (ss), circular, covalently closed (ccc) DNA associated with coconut foliar decay virus (CFDV) was purified, amplified by PCR and subcloned. Its sequence was established by analysis of overlapping subgenomic cDNA clones (Rohde *et al*. 1990). The complete sequence comprised 1291 nucleotides and contained open reading frames for six proteins of molecular weight larger than 5 kDa.

CFDV can be detected in coconut embryos and husks but not in pollen (Hanold and Randles 1997) emphasizing the need for efficient indexing of mother palms including the use of positive controls to confirm the reliability of diagnostic techniques. This is especially important given that the Vanuatu Tall, some of its hybrids and possibly other varieties are highly tolerant and can be infected without showing symptoms.

Problems and research needs

Much is known about coconut foliar decay virus. The insect vector is available for use in resistance screening and selection programmes for disease resistant germplasm, and sensitive diagnostic techniques are available for disease indexing. Transmission has not been reported via seed or pollen but detection of the virus in nuts and also in embryos collected from infected palms indicates that the risk of spread by this means needs to be investigated more intensively.

Viroid diseases: Cadang-cadang and Tinangaja

Cadang-cadang is a slow decline disease that results in premature death of coconut palms in the Philippines. The disease was first reported from a plantation in Albay Province on San Miguel Island in 1931. It is estimated that by 1980 it had killed more than 80 million palms on San Miguel and other neighbouring islands (Zelazny *et al.* 1982) but spread is generally slow (0.5 km a year). It causes yellow leaf spotting, reduced growth and reduced frond production which results in reduced crown size, cessation of nut production and eventual death within 5- 20 years. Cadang-cadang has been the major reason for prohibiting movement of Philippine coconut germplasm to many countries.

A similar disease known as Tinangaja occurs in Guam. Symptoms differ slightly from those of cadang-cadang in that nuts are characteristically small, elongated and lack a kernel (Boccardo *et al.* 1981). The disease was first reported as a destructive disease of coconut palms in Guam in 1917 (Boccardo 1985). It apparently spread slowly and destroyed the coconut industry of Guam over the next 40 years. No commercial coconut industry has existed in Guam since 1946 but the disease is still widespread on the island, with the incidence varying from one location to another.

Research on cadang-cadang disease began in the Philippines about 1950, and by 1982, the cadang-cadang viroid or CCCVd was identified as the causal pathogen (Zelazny *et al*. 1982; Hanold and Randles 1991a). This discovery provided a means of diagnosing the disease, and gave impetus to further research on related diseases (Hanold and Randles 1997), which showed that Tinangaja was also caused by a viroid (Boccardo *et al.* 1981).

Indexing

Cadang-cadang symptoms are not reliable means of detection and diagnosis owing to the ease with which they may be confused with the effects of other biotic and abiotic factors including diseases, pests, nutritional deficiencies, typhoons and lightning strikes. Although the disease can be mechanically transmitted to healthy coconut and other test plants (Imperial *et al*. 1985), indexing is impractical because the latent period between infection and appearance of symptoms is well over a year and symptoms, particularly in pre-bearing palms, tend to be non-specific. Pathogen detection and characterization by biochemical and molecular properties are thus of greatest significance for disease diagnosis and the safe movement of germplasm, particularly as the CCCVd can be detected in seed husks, embryos and pollen and may be spread by these means (Hanold and Randles 1997).

Pathogen characterization

Viroid purification

Viroids are the smallest known plant pathogens; and each consists solely of a small, circular, single-stranded, naked RNA molecule, which is infectious, and can replicate in the host cell and be transmitted independently of any other microorganism (Diener 1987). Reliable diagnosis is based on identifying the viroid RNA in extracts of coconut palms. Single-stranded RNA is very susceptible to degradation by ribonuclease, thus extraction from plant tissue involves the use of inhibitors such as phenol and SDS to minimize the risk of enzymatic degradation and antioxidants to prevent oxidation. The crude extract is then deproteinised, and viroid RNA precipitated with polyethylene glycol (PEG, mol. wt 6000). The resulting partially purified extract is ready for analysis by gel electrophoresis, or further purification by density gradient centrifugation (Hanold and Randles 1997).

Gel electrophoresis

Viroids migrate in most gel systems with a mobility less than that expected for their molecular weight. Various forms of CCCVd, which differ in size, are normally resolved in 5-20% polyacrylamide gels (Hanold and Randles 1997). Viroid bands are then visualized in the gel slab after staining with an appropriate stain such as silver, ethidium bromide, or toluidine blue. Increasing the temperature or pH of the gel buffer creates denaturing conditions, and causes viroids to denature from their native rod-like state to open circles and migrate more slowly than their linear forms. Diagnostic tests for viroids have been based on PAGE under both non-denaturing and denaturing conditions, and on the characteristic change of behaviour of these molecules when subjected to both sets of conditions. For example, in two-dimensional PAGE, transfer from a non-denaturing gel to denaturing conditions permits screening for all possible viroids. If used in conjunction with silver staining or molecular hybridization, the two-dimensional PAGE system is a sensitive and definitive test for the presence of small, circular nucleic acids in a preparation, and is thus a powerful tool in the detection of viroids (Hanold and Randles 1997). The procedure is however, lengthy and cannot be used on a routine basis.

Rapid diagnosis assay
For rapid diagnosis of cadang-cadang, an assay has been developed that involves three steps (Hanold and Randles 1997). Initially, sap is extracted from coconut leaf tissue and deproteinised. Then, nucleic acids are recovered by cold ethanol precipitation. Lastly, direct detection of the viroid is achieved by fractionation of the nucleic acids using PAGE and silver staining. The procedure is very sensitive, with a detection end-point of about 600 picograms of viroid. It is reliable and suitable for detecting viroids at the early stage of symptom development.

Molecular hybridization
After fractionation through PAGE, viroid bands on the gel slab are transferred onto a hybridization membrane and detected by molecular hybridization to a cDNA or cRNA probe (Hanold and Randles 1997). The technique is very sensitive and specific for viroid detection; cRNA probes are preferable to cDNA probes because they bind more strongly to the target RNA, giving stronger signals and thus allowing conditions of higher stringency for hybridization and reduce the non-specific binding of the probe.

Electron microscopy
Electron microscopy of purified samples spread under denaturing conditions can be used to identify circular viroid molecules and estimate their size (Randles and Hatta 1979). It cannot, however, be used for diagnostic purposes on tissue sections or crude extracts, since the small viroid rods and circles cannot be positively identified when mixed with other nucleic acids.

Characterization of viroid RNA
This requires a combination of the techniques described above. Isolation, purification, PAGE analysis, and electron microscopy can be used to establish that the nucleic acid is single-stranded RNA, circular in nature and in the size range 246 – 380 nucleotides which is typical of viroids (Keese and Symons 1987). The infectious nature can then be established by inoculating young palms with purified nucleic acids. Partial sequencing has made it possible to develop probes for specific detection of the viroids. Using these techniques, it has been shown that the cadang-cadang viroid is composed of two RNA molecules; the small 246/247 nucleotide (monomeric) and large 287/296/301 nucleotide (dimeric) forms, both of which are naked, single-stranded, circular, infectious by mechanical inoculation into coconut seedlings and are simultaneously isolated from infected palms (Randles and Hatta 1979; Mohamed *et al*. 1985). The small form is more abundant at the early stage of disease, but as symptom

development progresses, the larger form increases in quantity while the former decreases (Hanold and Randles 1997).

The Tinangaja viroid (CTiVd) molecule on the other hand, has 254 nucleotides, and has 64% overall sequence homology with CCCVd 246. CTiVd has not been shown to have the larger molecular forms described for CCCVd, but it does have a dimeric form (Boccardo *et al*. 1981; Keese *et al*. 1988). On the basis of their nucleotide sequences, CCCVd and CTiVd fall into the same viroid group.

Considerable confusion has been generated by the discovery of viroid-like sequences in a wide range of otherwise symptomless coconut and other monocotyledons from south Asia to French Polynesia (Hanold and Randles 1991b), including oil palms affected with an orange spotting (since shown to be a genetically inherited trait). Although the presence of these nucleic acid sequences could not be associated with any symptoms of disease or other adverse effects on the host plants, the observations led to a recommended embargo on the movement of germplasm from regions where they are found to countries where the viroid-like sequences have yet to be reported (Frison and Putter 1993). It is now considered that the risks were overstated and, in the absence of symptoms of disease, the presence of CCCVd-like sequences should not mitigate against such transfers (Frison *et al*. 1997).

Problems and research needs

The mode of natural spread of Cadang-cadang and Tinangaja diseases has not been established. The vector is unknown, transmission through pollen or seed has not been ruled out and eradication is not practical. Similarly, resistance has not been found. Although mild strains of other viroids are known to cross protect against severe strains, little is known about the natural occurrence of the mild strains of CCCVd. While the search for resistance continues, replanting of infected plantations has to be maintained in order to reduce production losses, as new plantings in diseased areas are not affected. The search for mild strains of the viroids should also be intensified.

Sensitivity, rapidity, simplicity and portability of diagnostic procedures for CCCVd for use in the field need to be improved so as to assist in studying the epidemiology of CCCVd and determining its mode of spread. Finally, quarantine restrictions on the movement of Philippine germplasm from affected regions have to remain in place until safer methods of exchange can be ensured but this need not be a hindrance to safe movement from other regions of the Philippines.

Protozoa disease: Phytomonas

Uniflagellate protozoa of the genus *Phytomonas* (Family Trypanosomatidae) are associated with and presumed to cause a group of diseases of coconut, oil palm and a few other palms in Central and South America (Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guyana, Nicaragua, Peru, Surinam, Venezuela) and the southern Caribbean (Grenada, Trinidad and Tobago) (Parthasarathy *et al*. 1976; Waters 1978; Dollet 1984). The disease is usually referred to as Hartrot but various local names have been used including Cedros wilt, Coronie wilt, fatal wilt and Marchitez sorpresiva and it is thought that these are all caused by variants of the same pathogen. Affected palms show rapid foliar discolouration and decay and usually die within 1-3 months from the first appearance of symptoms. The pathogen is normally restricted to the phloem but has been found in the husk, calyx, and coconut water in nuts of up to 11 months post fertilization but not in nuts showing advanced decay or in dry nuts (Nanden-Amattaram and Parsadi-Sewkaransing 1989). It is not known to be transmitted through seednuts or pollen but as with lethal yellowing, the risk of movement in seednuts cannot be completely ruled out.

Indexing

Symptoms usually start with yellowing or bronzing of the oldest leaves, loss of immature nuts and blackening of newly opened inflorescences and thus can easily be confused with those of lethal yellowing. However, the presence of the flagellates, which are 12-27µm x 1-1.5µm, can usually be confirmed in sap expressed from inflorescences or roots examined by light microscopy using phase contrast, dark field or after staining with Giemsa or toluidine blue (Waters 1978). All the coconut varieties that have so far been tested were susceptible to the disease, and other palms including *Bentinckia nicobarica*, *Elaeis oleifera, E. guineensis*, *Maximiliana maripa* and *Roystonia regia* may serve as alternative hosts (Dollet 1984; Kastelein and Parsadi 1986). The *Phytomonas* associated with Hartrot can be transmitted by pentatomid bugs of the genera *Lincus* and *Ochlerus* (Desmier de Chenon 1984; Dollet 1984) and these are thought to be the natural vectors of the disease.

Pathogen characterization

Although there are very few instances of protozoa being implicated in plant disease, *Phytomonas* have long been recognised as apparently harmless parasites of latex cells in laticiferous plants especially in the plant families Euphorbiaceae and Asclepiadaceae. Those associated with and thought to cause disease in coconut and oil palm have been described as *Phytomonas staheli* (McGhee and McGhee 1979) but the taxonomy of the genus, and the relationships between types pathogenic and parasitic in plants are not clear. Isolates from palms have been distinguished by means of isozyme profiles (Guerrini *et al*. 1992), restriction length polymorphisms of kinetoplastid DNA (Muller *et al*. 1995) and from sequences of small subunit 18S rDNA (Marche *et al*. 1995). However, in practice, demonstration of the presence of flagellates in palm tissues should be sufficient for presumptive diagnosis of the disease. According to Ohler (1999), in addition to other palms, Musaceae and Zingiberaceae are now thought likely sources of the disease. Precautions to ensure safe movement should thus be extended to these species, particularly to vegetative propagation materials.

Nematode disease: Red Ring

Red ring disease is caused by the nematode *Bursaphelenchus* (*=Rhadinaphelenchus*) *cocophilus* and is spread mainly by the palm weevil *Rhycopophorus palmarum* and also the sugarcane weevils *Dynamis borassi* and *Metamasius hemipterus* (Giblin-Davis 1993), The disease occurs throughout Central and South America, Mexico (Yucatan peninsula), the Lesser Antilles and the Dominican Republic but has not yet been reported in Cuba and Jamaica despite the presence of the weevil vectors in these countries. Young palms (3-10 years old) are reported to be most frequently affected and die within a few months of infection, which takes place through wounds associated with weevil activity. Symptoms vary according to age, variety and growing conditions but may include yellowing or bronzing of leaves (usually the oldest first but sometimes discontinuously within the crown), nutfall and necrosis or withering of newly opened inflorescences. Production of small and sometimes distorted young leaves ('little leaf' syndrome) has reportedly been associated with the disease in parts of South America (Hoof and Seinhorst 1962).

The characteristic and diagnostic feature of the disease is an internal red discolouration at the base of the stem in the form of a ring about 2-6 cm wide and about 3-5 cm from the periphery. The red ring usually extends 2-3 m up the stem, breaking up into streaks or discrete spots, which may extend into the rachis and petiole, and into cortical tissues of the roots. The discoloured palm tissues contain abundant nematodes (adult stages are about 1mm long). Juvenile stages of the nematode parasitize palm weevil larvae that develop in infested palms which remain infected throughout metamorphosis. They then transmit the nematode to healthy palms primarily during oviposition in moist leaf bases or freshly wounded tissues (Gerber and Giblin-Davis 1990).

The disease can usually be diagnosed reliably from the presence of internal symptoms, confirmed by observation of nematodes in palm tissues, and no special indexing or characterization techniques have been described. Although it has been shown that artificially inoculated seednuts supported nematodes for up to 16 weeks after germination, none could be found after 20 weeks and the developing seedlings remained free of disease (Giblin-Davis 1991), suggesting that spread of disease is unlikely to occur in seednuts. However, the movement of germplasm from red-ring affected regions should follow the general recommendations in the FAO/IBPGR Technical Guidelines (Frison and Putter 1993).

Conclusion

Perhaps the biggest threat to the safe movement of coconut germplasm remains from diseases of as yet unknown or uncertain aetiology, or perhaps not yet recognised as infectious conditions at all. The aetiology of several diseases on the Indian subcontinent remains uncertain or unconfirmed: root wilt and Tatipaka on the west and east coasts of India; leaf scorch decline and premature decline in Sri Lanka. Information on transmission of these diseases through seednuts, embryos or pollen is sorely lacking and experimental investigations are hampered by the lack of reliable diagnostic methods and the obvious difficulties in carrying out large-scale, long-term empirical testing by direct observations on progenies and crosses from diseased palms. Elsewhere, there are several instances where 'new' diseases, either previously unrecognised or of only minor local importance, have emerged following the introduction of exotic coconut varieties to new regions. Budrot and premature nutfall cased by *Phytophthora palmivora* were recognised as only minor problems in indigenous varieties grown in north Sulawesi, Indonesia, but caused widespread losses following the large-scale introduction of exotic Malayan Dwarf x West Africa Tall hybrids in the 1980s. Outbreaks of so-called coconut stem necrosis were also associated with the introduction of exotic varieties in Indonesia (Turner *et al*. 1979) and the emergence of foliar decay virus as a problem in cultivars introduced to Vanuatu as referred to earlier. In South America, lethal diseases of unknown aetiology, the so-called spear rot-bud rot complex, affect oil palm in several countries (de Franqueville 2002). It is possible that these diseases will affect coconut, emphasizing the need for caution when considering the movement of coconut germplasm.

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Strategies for safe movement of coconut germplasm

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The drastic effects of plant diseases on yield, on plant growth and on landscapes can be seen in many different agricultural as well as natural habitats. Few diseases have as drastic effects as the so-called lethal ones, such as the lethal yellowing disease (LYD) that killed millions of coconut palms. The coconut research community is therefore very much aware of risks due to pests and pathogens. Like many other plant diseases, LYD is also reported as spreading to new areas, after the Gulf and Caribbean coasts of Mexico, Belize and Honduras now to the Pacific coast of Mexico (Harrison *et al.* 2002). This disease is caused by a pathogen that belongs to the group called 'phytoplasmas', or formerly mycoplasma-like organisms (MLO). The pathogen is transmitted by a planthopper, a small insect. Recently, a yellowing disease associated with phytoplasma was reported to occur on date palms in Kuwait (Al-Awadhi *et al.* 2002). It seems that the pathogen is not only spreading to new areas, but also to new hosts.

Some plant pathogens spread to new areas as wind-blown spores, e.g. the coffee rust fungus *Hemileia vastatrix* that appeared in 1970 in Brazil, and moved from there to all coffee producing areas in South and Central America as well as in Mexico. Little can be done to prevent the spread of such a pathogen. Other pathogens, for example viruses and phytoplasmas, and many fungi, move only with the help of a vector, such as an insect, or an infected plant to new areas. Here, at least in theory, preventing the movement of insect vectors or infected plants will prevent the spread of the pathogen. Phytosanitary measures can help to stop the introduction of non-indigenous, potentially damaging pests and pathogens into an area or to eradicate them before they spread and cause serious yield losses or the death of plants.

There is no doubt that activities to strengthen the conservation and use of plant genetic resources worldwide, with special emphasis on the needs of developing countries, are of utmost importance. However, care must be taken not to introduce new pathogens inadvertently. With the high genetic diversity of plants, a diversity of pathogens is often associated. The diversity of plant genotypes is much needed for the selection of resistant varieties, which maybe the only promising control strategy for some plant diseases. The above mentioned lethal yellowing disease of coconut could be effectively controlled using resistant varieties, such as Malayan Dwarf hybrids.

Clearly, the movement or plants or plant parts between countries or continents entail the risk of introducing exotic plant pests or pathogens. Less-developed countries often lack adequate plant quarantine and diagnostic facilities, and are especially vulnerable to the damaging effects of newly introduced diseases. It is extremely important that the risk is recognized, and that a minimum risk transfer form of germplasm is chosen, such as *in vitro* plantlets instead of nuts. Networks, such as International Coconut Genetic Resources Network (COGENT), assist their members with pest risk analysis procedures.

An effective phytosanitary system acts as a filter and not a barrier to germplasm exchange. It keeps pathogens out and allows germplasm to pass. As some countries have stronger systems than others, the plant breeders and the germplasm community should also give due attention to pathogens. In addition to the risk of spreading pathogens to new areas (there are numerous examples where this has happened with germplasm), there is also the risk of the collections, or part thereof, being destroyed by disease epidemics. This risk is particularly high in field genebanks.

The choice of phytosanitary measures (exclusion, import permit stating certain conditions, certification according to the requirements of the importing country, standard quarantine certificate, post-entry isolation and observation) depends on the risk. The instrument of pest-risk analysis helps to make the correct choice, provided the required data are available (see articles by de Franqueville and Ikin in this chapter).

Since phytosanitary measures were established (in some countries almost 100 years ago), the justifications for quarantine measures have not changed:

- The pest or pathogen does not occur in the importing country;
- The pest or pathogen is capable of surviving and multiplying under the conditions of the importing country; and
- The pest or pathogen is likely to cause economic damage.

The International Plant Genetic Resources Institute (IPGRI), has published jointly with the Food and Agricultural Organization (FAO) Technical Guidelines for the Safe Movement of Germplasm (e.g. Frison *et al.* 1993 for coconuts). Table 1 summarizes the FAO/IPGRI Technical Guidelines for the Safe Movement of Coconut Germplasm. The general recommendation is to move embryo cultures or pollen, and not seednuts. If this recommendation is followed, the risk of moving fungi, phytoplasma (MLO) and the red ring nematode with germplasm is greatly reduced.

Indexing would be required only for germplasm from Vanuatu (for coconut foliar decay virus), Guam (for tinangaja viroid), and from parts of the Philippines (for cadang-cadang viroid), unless one decides to exclude material from these areas from germplasm movement. Based on this, the priority should be on supporting embryo culture facilities and training.

Since the publication of these guidelines, further research was conducted. To date, no disease symptoms could be linked to the presence of viroid-like sequences in coconuts. They were found to be widely distributed in coconuts and understorey plants. Presumably they do not play a role as pathogens (Diekmann 1997, FAO/IPGRI 1997). It is important not to confuse the cadang-cadang viroid with viroid-like sequences. Cadang-cadang viroid causes premature death of coconut palms in parts of the Philippines (see article by Eden-Green and Mpunami in this chapter). Viroid-like sequences were detected by molecular methods in coconuts and other monocotyledons, but could not be associated with disease symptoms (Hanold and Randles 1991).

On the other hand, the reported non-transmission of phytoplasmas (through seed, embryo culture or pollen) may need to be reconsidered. Cordova *et al.* (2003) reported the presence of phytoplasma DNA in embryos from nuts of palms suffering from lethal yellowing disease. Current opinion among plant pathologists is that phytoplasmas are not transmitted by seed because there is no vascular connection between the tissue of the parent plant and the embryo (Jones 2001). Further investigation is needed to clarify whether the presence of phytoplasma DNA in the embryo incidates the risk of seed transmission or not. Furthermore, the transmission rate under field conditions needs to be studied. As premature nut fall is one of the first signs of the disease, nuts (if at all produced) may not germinate properly, reducing the risk of further transmission through seed/embryos.

Germplasm health needs to be considered not only at the point of exchange, but at any stage of germplasm management (collecting, multiplication, evaluation and characterization, storage and distribution). Cooperation among breeders/germplasm curators and regulatory organizations is essential. Consultation should occur regularly, particularly at early planning stages for collecting, establishing field genebanks, etc. Germplasm should be exchanged only for immediate use or for safety duplication.

Table 1. Summary of FAO/IBPGR Technical Guidelines for the Safe Movement of Coconut Germplasm
Source: (Frison et al. *1993)*

Pathogen	Specific Recommendation(s)
Coconut foliar decay virus (CFDV)	Indexing or exclusion of germplasm from Vanuatu
Coconut cadang cadang viroid (CCCVd)	Indexing or exclusion of germplasm from the Philippines
Tinangaja viroid (CTiVd)	Indexing or exclusion of germplasm from Guam
Viroid-like sequences	Indexing recommended for germplasm that is moved from countries where these sequences are known to occur to countries where they have not yet been reported.
Lethal yellowing (Phytoplasma, MLO)	Transmission through seed, embryo culture or pollen not reported
Kerala wilt (Phytoplasma, MLO)	
Tatipaka disease (Phytoplasma, MLO)	
Blast (Phytoplasma, MLO)	A nursery disease which does not occur on adult trees
Marasmiellus spp. (bole rot, shoot rot)	Possibly seed-borne, can be eliminated in embryo culture
Phomopsis cocoina (leaf spot) *Bipolaris incurvata* (leaf blight)	May be dispersed on husks. Recommendations are: • Embryo and pollen transfer should be carried out • Healthy nuts should be partially de-husked and treated with an appropriate fungicide
Phytophthora palmivora, P. katsurae (bud rot, fruit rot)	Nuts may be infected internally, but then do not germinate. Recommendations are: • Embryo and pollen transfer should be carried out • Healthy nuts should be partially de-husked and treated with an appropriate fungicide

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Pest risk assessment of the International Coconut Genebank for Africa and Indian Ocean, and Latin America and the Caribbean

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Introduction

The International Coconut Genetic Resources Network (COGENT) of the International Plant Genetic Resources Institute (IPGRI) has been assisting the establishment of a multi-site International Coconut Genebank (ICG), with sites in five countries, each representing one of the main coconut ranges. They are Indonesia for Southeast Asia, India for South Asia, Papua New Guinea for the South Pacific, Côte d'Ivoire for Africa and the Indian Ocean, and Brazil for Latin America and the Caribbean region.

The pest pressure exerted on coconut throughout its major producing regions, and the consequent phytosanitary risks to which it is exposed, are a threat to its sustainability and sometimes lead to it being dropped from a production system. The risks are rarely the same worldwide, and are therefore important to assess them in order to promote germplasm dissemination and exchange under optimum conditions.

Generally, it is the overall phytosanitary constraint that needs to be documented in a given zone, not only to avoid the transfer of pests and diseases but also to guarantee a satisfactory phytosanitary situation in the collections planted at a given site. That means also taking into account fungal diseases and the main coconut pests in the entomofauna that are likely to jeopardise the establishment of a germplasm collection.

In order to determine this constraint, a pest risk assessment was conducted in two ICG host countries, Côte d'Ivoire and Brazil. This paper attempts to document the main pests and diseases in the study zones, analyse the corresponding phytosanitary risk, determine their potential as quarantine organisms and identify the phytosanitary risks involved for collecting and exchanging germplasm.

Material and methods

Documentation

This study is based on all the information gathered by conventional bibliographical research, the author's knowledge of coconut diseases, or oil palm diseases in some cases that could impact on coconut, consultations and discussions with members of the scientific community, supplemented by information gathered from some particularly useful internet sites.

Visits to ICG host countries: Côte d'Ivoire and Brazil

The visit to Côte d'Ivoire took place in April 1999, in liaison with the Marc Delorme Research Station (Centre National de Recherche Agronomique, CNRA). Sites visited included the station itself, at Port-Bouët, near Abidjan, with its current collection; the lagoon strip between Assinie and the Ghanaian border, to examine the condition of the coconut groves; and the Grand-Drewin Experimental and Production Station (CNRA, Gagnoa regional management), a potential site for a future collection. This station is located at Sassandra, around 240 km from Port-Bouët, and around 330 km from the Ivorian-Ghanaian coastal border. Port-Bouët is around 95 km from the same border (all the distance are direct, as the crow flies). The Ghanaian border at Elubo is around 170 km by road, via Aboisso, from Port-Bouët and 460 km from Sassandra.

These details are important, due to the existence of lethal yellowing disease (LYD) in the neighbouring Ghana. Arrangements will have to be made to duplicate all or part of the Marc Delorme Station collection at the Grand-Drewin Station if the disease gets any closer to the Ivorian border.

The visit to Brazil took place also in April 1999, in liaison with the EMBRAPA research station at Aracaju, in Sergipe State (Centro de Pesquisa Agropecuária dos Tabuleiros Costeiros - Empresa Brasileira de Pesquisa Agropecuária). The sites visited that are candidates for receiving the future ICG material were Itaporanga, west of Aracaju, the Neopolis plateau, northeast of Aracaju, and Betume, located between Neopolis and Ilha das Flores.

Pest risk assessment

Pest risk assessment is a step towards a pest risk analysis (PRA), following the process laid down by FAO (1996a, b). Its purpose is to identify pests and diseases necessitating plant quarantine. It is carried out in a potentially or known pest risk area, usually a country. Ikin (1997) applied these directives to coconut germplasm exchanges for cadang-cadang and cadang-cadang viroid-like sequences. His study led to the revision of the directives governing germplasm movement and the quarantine measures applied to it.

PRA could be broken down into three stages:

1. *Identification of pests or pathways* for which PRA is necessary. Here, the pathway is defined by the form in which germplasm is

transported: seedlings, seeds, pollen or embryo culture. A pest may or may not be defined as being a quarantine organism depending on the germplasm form;

2. *Risk assessment* serves to determine whether the identified organism, as such or combined with the pathway, is a quarantine organism, depending on its likelihood of entering the PRA zone, the capability of establishing itself and spreading, and its economic importance (Diekmann 1997).
3. *Risk management* comprises the development, assessment, comparison and choice of options intended to reduce that risk.

PRA can be carried out by considering either the pathway or the pest (i.e., the form in which germplasm should be exchanged to significantly reduce the risks of introducing a given pest). It is primarily the second approach that will be taken, given the inventory of pests existing in the study areas.

Results

Coconut diseases and pests

Almost 30 diseases affect coconut worldwide (Frison *et al*. 1993; Ikin 1997; Mariau 1999). Most are found on the Asian continent and little is known about most of them. In the study areas, neither identified diseases of viral nor viroid origin have been inventoried. On the other hand, LYD shows a strong presence in Africa, Central America and the Caribbean.

The insects listed during the study do not figure in the germplasm transfer pathways, given their nature and their biology, although special attention must be given to the recent outbreaks of white flies (*Aleurotrachelus atratus* and *Paraleyrodes bondari*) in Comoros Islands (Baudoin and Ollivier 2003, personal communications). However, it is possible that the insect pests do pose a threat for the installation and development of collections in Côte d'Ivoire and Brazil. Mites, especially *Eriophyes guerreronis*, can be harboured by nuts, primarily beneath the floral parts, and are therefore, a risk that has to be considered if germplasm is moved as seednuts. However, as they cannot withstand a vacuum (JF Julia 1999, personal communication), there is little risk of them contaminating pollen. Likewise, it should be possible to detect any contamination of embryo cultures very rapidly.

For the record, vertebrate pests, birds or mammals do not figure in the germplasm exchange pathways, but the risks they represent to collections, especially on young plants, need to be taken very seriously. In general, cultural practices or special arrangements (ditches, fences) help to reduce their impact.

Situation in Africa/Indian Ocean

The following seven diseases were found in Africa and the Indian Ocean:

Phytoplasma diseases

Blast is the main nursery disease on oil palm in Africa, and is also found on coconut (Quillec *et al.* 1978). It is attributed to a phytoplasma due to the preventive role played by tetracycline (Dollet 1980; Dollet 1985). Blast is carried by a leafhopper, *Recilia mica* Kramer (Desmier de Chenon 1979). The insect only seems to be infectious at certain times of the year and incubation lasts a few days (de Franqueville *et al.* 1991). Blast has never been reported on bearing palms, although it has been observed during the first year after planting. Therefore, it is not a major threat to germplasm movement.

LYD first occurred in Africa around 1930 (Bachy and Hoestra 1958), in Togo and was called Kaincopé disease (Dollet and Giannotti 1976), then in Southeast Ghana as Cape St Paul wilt (Dabek *et al*. 1976), in Cameroon as Kribi disease (Dollet *et al*. 1977) and in Nigeria asAkwa disease (Ekpo and Ojomo 1990). In East Africa, LYD causes serious damage in Tanzania (Schuiling and Mpunami 1990), Kenya and Mozambique (Mpunami *et al*. 1996). Analyses by restricted fragment length polymorphism (RFLP) and polymerase chain reaction (PCR) suggest a degree of difference between West African and East African phytoplasmas (Tymon *et al*. 1997, 1998). The disease vector has not been formally identified, but a plant hopper, *Myndus adiopodoumeensis* is strongly suspected in Ghana (Dery *et al*. 1996). Phytoplasma diseases are considered to have little chance of being carried by seeds, pollen, or embryos (Dollet 1995). Phytoplasmas seem to have been detected in embryos, but there is no evidence that these embryos would normally germinate.

LYD is not widespread throughout the African and Indian Ocean region; it has not been reported in Côte d'Ivoire, Benin or the Seychelles.

Fungal diseases

Phytophthora katsurae Ko and Chang causes immature nut fall and lethal bud rots (Quillec and Renard 1984). *P. katsurae,* which was initially identified as *P. heveae*, a very closely related species, seems to be the only fungal species, found damaging in Côte d'Ivoire (Blaha *et al*. 1994). Its incidence is effectively controlled by fungicide injection into the stem (de Franqueville and Renard 1989). *Phytophthora* rot diseases are not documented in the other African countries, but are suspected in Ghana.

Marasmiellus cocophilus Pegler is associated with the so-called lethal bole rot, on seedlings or young palms in Kenya and Tanzania (Bock *et al.*

1970). The fungus can act as a saprophyte, colonizing plant matter, either from coconut palms or from other crops.

Phomopsis cocoina (Cooke) Punith. causes leaf spots and husk rot. It is reported in Kenya, the Seychelles (quoted by Frison *et al*. 1993). It can be borne by nuts.

Bipolaris incurvata causes leaf blight in the Seychelles. This symptom is similar to the *Helminthosporium* leaf spot found in Côte d'Ivoire (Quillec and Renard 1975), caused by *Helminthosporium halodes* (Dresch.), whose limited economic importance has never warranted any intensive intervention.

Diseases of unknown origin

Dry bud rot, which is documented in Côte d'Ivoire (Renard *et al*. 1975), also found on oil palm, is transmitted by two similar species of *Delphacidae*, namely *Sogatella kolophon* Kirkaldy and *S. cubana* Crowford (Julia and Mariau 1982). It is a disease of young palms and primarily occurs in the nursery; damage to adult palms has not been observed. There is no information available on its incidence in the other countries of West Africa.

Pest risk assessment in Côte d'Ivoire

Ivorian coconut plantings are subject to four of the seven diseases documented in Africa and the Indian Ocean. Two are diseases found in the nursery or on young palms - blast and dry bud rot. The other two are fungal diseases, namely: *Helminthosporium* leaf spot and *Phytophthora*.

LYD, in neighbouring Ghana, is spreading and threatening the eastern part of Côte d'Ivoire, but it is difficult to establish the speed with which the disease is spreading. In the Western Region, it first occurred in 1964 at Cape Three Points. It was not until 1992 that it reached Axim, around thirty kilometres to the West, after affecting Cape Coast in 1984, 100 km to the East. The situation has been described by Philippe (1997): a large focus developed around 15 km west of Axim, i.e. around 74 km from the Ivorian border. A smaller focus was detected 13 km to the West (61 km from Côte d'Ivoire) and two diseased palms were detected 34 km from the border. Those two palms were immediately eliminated. By 1999, the situation had barely changed (R. Philippe 1999, personal communication). The larger focus, near Axim, has spread at a rate of one to two km per year, the smaller focus at a rate of around a hundred metres in two years, and the situation has remained unchanged at the site where the two diseased palms were eliminated.

Visits to the lagoon strip, on the Ivorian side, did not reveal any lethal yellowing infection. There were some yellowing palms, in poor condition, with few or no bunches but there were no signs of any developments in either symptom intensity or dispersion of the symptoms. They are old coconut palms, which have never received any fertilizer or phytosanitary treatment and have always be subjected to attacks from *Oryctes* and scale insects (*Aspidiotus destructor* Signoret), which should not be confused, as emphasized by Dollet (1995) with cases of lethal yellowing.

The Grand-Drewin station is one of the sites selected for establishing a coconut germplasm collection. It also has a large population of oil palm. There is no *Phytophthora* disease.

Given its location in a low rainfall zone, the risks run by the collection are linked to drought unless an irrigation system is installed. Diseases affecting young palms may also occur (blast and dry bud rot), which can be effectively controlled by chemical treatments against the vectors, and by cultural practices. A close watch will have to be kept on *Oryctes* sp. outbreaks in the early years after planting, especially if old oil palm plantings have been felled in the vicinity. During production periods, Aceria (*Eriophyes guerreronis*) damage is to be feared. Damage caused by the Coreid bug *Pseudotheraptus* sp. is slight, probably due to the good establishment of *Oecophylla* ants, which limit its development.

Lastly, it is reasonable to assume that if LYD were to spread into Côte d'Ivoire, it would probably only occur on a scale of at least one generation of coconut palms.

Situation in Latin America and the Caribbean

At least the following ten diseases are documented in Latin America and the Caribbean (LAC):

Phytoplasma disease

LYD was reported for the first time in the Cayman Islands around 1830, has spread throughout the Caribbean, to Haiti, the Dominican Republic, Cuba, Jamaica and then Florida. It reached the Yucatan peninsula in Mexico in the 1980s (Cardeña *et al*. 1991) and was reported in Honduras in 1996 by Ashburner *et al.* Its spread in LAC has been much faster than in West Africa and it is carried by a leafhopper, *Myndus crudus* Van Duzee (*Cixiidae*). Molecular techniques (RFLP, PCR) have shown greater similarity between the phytoplasmas in LAC and East Africa than with those in West Africa (Jones *et al*. 1995; Tymon *et al*. 1998). LYD occurs in most of the countries in the zone in the COGENT network, but not in Costa Rica, Guiana, Trinidad and Tobago, and Brazil. It also doest not exist in Nicaragua or Venezuela.

It should be noted that phytoplasmas are reported to have been detected in the embryos of nuts from diseased palms in Mexico. It has not been confirmed, but needs to be checked as soon as possible, using all the appropriate techniques (electron microscopy, PCR), along with their viability.

Fungal diseases

Phytophthora palmivora and *Phytophthora katsurae* live side by side in Jamaica (Steer and Coates-Beckford 1990), but *P. palmivora* is usually the only species found in the zone. It causes bud rot leading to the death of coconut palm. Its incidence can be devastating in some parts of the Caribbean, notably the Dominican Republic. It is known to exist in Cuba and Central America, but there is no precise information. *Phytophthora* rot diseases are not documented in Brazil. Bud rot symptoms have been observed in the Fortaleza region of Ceara state and have been assimilated in their advanced stage to those caused by this fungus. However, neither the development of the disease, nor the isolations carried out, has confirmed this hypothesis (de Franqueville 1996).

Bipolaris incurvata occurs in Central and South America. In particular, it was reported in Brazil by Warwick (1997) where it causes *Helminthosporium* leafspot, or 'mancha-foliar', particularly in the nursery.

Lixa pequena, caused by *Phyllachora torendiella* (Bat.) nov.comb., is a widespread leaf disease in Brazil of varying intensity (Subileau *et al*. 1993). It is also found in French Guiana. It can cause up to 50% loss of leaf area, immature nut fall, and consequent yield loss of 20 to 40% (Renard 1999). Lixa grande is another leaf disease associated with the previous one but caused by *Sphaerodothis acrocomiae* (Montagne) von Arx & Muller. Queima das folhas is also a leaf disease of Brazil, caused by *Botryosphaeria cocogena* Subileau. Lixas generally promote the development of this fungus, for which they represent access routes. This constitutes a perfect parasitic complex (Subileau 1993, 1994; Warwick *et al.* 1994).

Phytomonas disease

Hartrot is endemic in northern South America, from Peru or Bahia state in Brazil, to Costa Rica (Renard 1999). It is moving up to Honduras, where infected oil palm marchitez is already found. It has also been identified in Trinidad, under the name of *Cedros wilt*, where 15 000 coconut palms have been killed in three years. It causes sporadic damage in Colombia, Venezuela, Surinam, Brazil and French Guiana. Smallholdings, which do not have access to regular insecticide treatments, can disappear within five years (M. Dollet 1999, personal communication). The presence of *Phytomonas* (Trypanosomatids) is associated with any Hartrot syndrome (Dollet *et al.* 1977a; Dollet and Lopez 1978). Hartrot is carried by bugs of the *Lincus* genus (Louise *et al*. 1986) or *Ochlerus* genus (Mariau 1985).

Nematode diseases
Red ring disease is caused by *Bursaphelenchus cocophilus* (Cobb) Baujard, a nematode carried by an insect, *Rhynchophorus palmarum* (*Curculionidae*). It is endemic in Central America, South America and the Caribbean (Warwick *et al*. 1995). This disease also affects oil palm. Its incidence varies depending on the region. In Venezuela, some oil palm plantations have suffered 70% losses in 15 years. Red ring control consists of limiting the vector populations, notably by using aggregation pheromones.

Diseases of unknown origin
A dry bud rot occurs in Brazil (Renard 1990). It is not known whether it is linked to the one found in West Africa and/or with the so-called oil palm ring spot disease, which is rife in Latin America, although symptoms are similar to those of oil palm dry bud rot in West Africa. As knowledge stands at the moment, it is classified as a juvenile disease in Brazil (Warwick 1998).

Porroca is a disease of unknown origin that seems primarily to affect poorly maintained coconut plantings. Currently, its incidence seems to be limited to Colombia and Panama, countries which are not in the COGENT network. Porroca is not reported in Costa Rica for the time being, but it is worth monitoring closely in Central American countries. Similar symptoms (short leaves) exist in French Guiana.

Pest risk assessment in Brazil
Seven of the 10 diseases listed above are found in Brazil, but the two most serious diseases have not been detected in the country, i.e. lethal yellowing and *Phytophthora*. Several thousand kilometres separate Brazil from the most active lethal yellowing foci, whether in the Caribbean zone or in Central America. The Andes, in Colombia and Venezuela, also form a natural barrier between Brazil and the Central American foci. It is therefore unlikely that lethal yellowing will occur in epidemic proportions in Brazil.

Brazil may be a favourable zone for *Phytophthora palmivora* development, as shown by attacks on cocoa plantings in Bahia state (Ortiz Garcia 1996).

The Aracaju region in Sergipe is characterized by a substantial water deficit and by extended periods of severe drought. The predominant diseases in the region are leaf blights (lixas and queima das folhas), which occur in varying degrees in each of the plantations visited. Hartrot only seems to occur sporadically in the region (DRN Warwick 1999, personal communication).

Wherever the collection is planted, it will run the risk of dry bud rot, which can cause major damage in young plants (Warwick 1998), and

Helminthosporium leaf spot. However, attacks can be limited by preventive treatments.

The list of coconut pests in Brazil is long (Ferreira *et al*. 1998; Morin 1986). The pests that are likely to be a threat to the collection are primarily *Brassolis sophorae* L., *Hyalopsila ptychis* Dyar, *Coraliomela brunnea* Thumberg, *Homalinotus coriaceus*, *Aspidiotus destructor* Signoret and the mite, *Eriophyes guerreronis* Keifer.

Generally speaking, a close watch will have to be kept on the germplasm collection to prevent the risks associated with these different pests. If free of any lethal diseases, drought will remain the main limiting growth factor of the germplasm collections in Brazil.

Risks linked to germplasm exchange in the study zones

From African/Indian Ocean countries to Côte d'Ivoire

Lethal yellowing is a threat to Côte d'Ivoire. The causal agent is capable of surviving in this country, spreading and causing major economic damage. It is therefore a potential quarantine organism.

As far as fungal diseases are concerned, the risk of introducing *Marasmiellus cocophilus*, which has yet to be reported in Côte d'Ivoire, exists from Kenya to Tanzania. *Phomopsis cocoina* is reported in Kenya and the Seychelles and can be borne by nuts. *Bipolaris incurvata* is also reported in the Seychelles, but causes only minor damage, except in the nursery. *Helminthosporium* leaf spot occurs in Côte d'Ivoire. These fungi are not a major threat for coconut cultivation in Côte d'Ivoire and their economic importance does not warrant their being considered as quarantine organisms. *Phytophthora palmivora*, a species not found on coconut in Côte d'Ivoire, has not been reported in the countries of the zone.

From Côte d'Ivoire to African/Indian Ocean countries

Phytophthora katsurae may be a threat for the other countries in the zone involved, but only causes immature nut fall at the Marc Delorme Station. Hence, nuts do not germinate. The Grand Drewin Station is free of it. Moreover, it can be effectively controlled by appropriate fungicide treatments.

For the other fungal diseases, only *Helminthosporium* leaf spot could be a threat, but methods of control and prevention exist for this disease. It only significantly affects certain ecotypes and is of no economic importance.

Dry bud rot and blast are juvenile diseases that only occur at certain times of the year with virtually non existent risk of transmission.

From Latin American/Caribbean countries to Brazil

There is nothing to indicate that the causal agent of lethal yellowing is not capable of settling, developing and causing serious economic damage in Brazil, even in the marginal zone of Aracaju. *Myndus crudus*, the disease vector in Florida and Mexico, has also been seen on oil palm plantations in Para state (Julia 1990). In any event, the Brazilian government has stepped up its quarantine and surveillance measures for palms to prevent the introduction of lethal yellowing in the country.

Phytophthora palmivora probably exists in all the countries in the zone. The recurrent drought in Sergipe and the Aracaju region should hinder the establishment of this pathogen and limit its possible economic impact.

From Brazil to the other countries of Latin America/Caribbean

The economic importance of leaf fungi, *Lixas* and *Queima*, in Brazil means that considerable attention needs to be paid to the movement of the parasites involved. They exist in Sergipe, but also in other much more humid zones, such as Para state, where disease incidence is relatively contained by hyperparasitic fungi, *Septofusidium elegantulum* or *Acremonium alternatum* (Warwick *et al.* 1998). There is nothing to indicate that they are present in the other countries in the zone. Possible transmission of this fungus by pollen has been suggested, although not proven. In any event, based on the available information and given the lack of any effective control method, they have to be considered as quarantine organisms, be it via pollen or seeds.

Hartrot disease occurs sporadically in Sergipe. With the exception of Trinidad and Tobago, it has not been reported in the Caribbean zone and therefore could be a threat from Brazil to Cuba, Haiti and Jamaica. Because of its causal agent, which also exists in Grenada on Alpinia, and the economic damage it causes, it should be considered as a potential quarantine organism for those countries and for Mexico. However, its intraphloemic nature ought to limit the risk of transmission by pollen or embryos. Red ring disease, which is endemic throughout Latin America and part of the Caribbean, should not be a major threat provided precautions are taken to eliminate the vector. Dry bud rot, as knowledge stands at the moment, is a juvenile disease with virtually non existent risk of transmission.

Recommendations

The technical directives drawn up by the FAO impose a few basic measures that govern coconut germplasm movements. Among the measures worth noting in particular, is that such movement must be by embryo cultures or pollen, using the techniques described in the recommendations of the FAO.

It is common sense that germplasm should only be collected from healthy palms (not from the ground) at sites free of serious diseases. In that way, movement of partially dehusked and carefully decontaminated nuts, as recommended by the FAO for most fungal diseases, should not involve any major risks of spreading lethal diseases. It is all the more important in view of the fact that very few countries in the COGENT network have embryo culture facilities as yet.

The two ICG host countries, Côte d'Ivoire and Brazil, are countries free from LYD, unlike most countries in the zone they represent.

Any germplasm movement to these two countries must be by pollen or embryo cultures, seeing that LYD propagation is not possible by those pathways. Occasionally, seednuts could also be used provided they are collected from zones free of LYD or Hartrot, as certified by the exporting countries through a phytosanitary certificate after the evaluation of the collection site. If movement is by seednut, particular care must be paid to mites, with fumigation where necessary.

It cannot be ruled out that *Phytophthora* may have an airborne phase during its cycle and contaminate pollen. This hypothesis is difficult to confirm or refute. Pollen preparation does not eliminate the fungi, but the measures recommended by the FAO (inspection and search for fungi on leaving the exporting country and on entering the importing country) should enable checks to be made notably by using specific *Phytophthora* culture media.

Germplasm movements from Brazil to the other countries in the LAC zone must take into account the risks of propagating leaf diseases that are widespread in Brazil. As knowledge stands at the moment, it is not possible to say that the causal agents are not conveyed by seednuts or pollen. Moreover, they are difficult to isolate and culture, which does not argue in favour of the phytosanitary inspection recommended for *Phytophthora*. Embryo culture is therefore recommended for germplasm exported from Brazil.

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Pest risk analysis and guidelines for the safe movement of germplasm in the International Coconut Genebank of Asia and the Pacific

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Introduction

Pest risk analysis (PRA) or Import risk analysis (IRA) is the process that is used to technically justify phytosanitary measures that are imposed on the importation of plants and plant products. Although the process is primarily used to determine import conditions for commercial quantities of traded commodities, it must be applied also to importations of small quantities of germplasm because in both cases there must be technical justification for the phytosanitary measures imposed. International guidelines for the pest risk analysis methodology have been developed by the Interim Commission on Phytosanitary Measures (ICPM) under its mandate to harmonise plant quarantine/phytosanitary procedures at a global level under the World Trade Organisation's Sanitary and Phytosanitary Agreement (SPS Agreement). The two main International Standards for Phytosanitary Measures (ISPMs) are #2 Guidelines for pest risk analysis (FAO 1996a) and #11 Pest Risk Analysis for quarantine pests (FAO 2001). The identification of pests of concern in the movement of germplasm and the formulation of phytosanitary conditions for the management of these pests were initially developed at an international level by FAO/IPGRI (Frison *et al.* 1993; Diekmann, this chapter). Later, this publication was modified for one key pest using the ISPM Guideline for PRA methodology at the ACIAR/COGENT/IPGRI meeting in Malaysia (Diekmann 1997).

The purpose of this article is to examine the process of PRA in more detail, to identify major pests of concern at a global level and to suggest pest management options that are available that could be adopted at national or regional level to reduce pest risk to an acceptable level. In this case, the task is to devise pest management strategies for the exchange of seednuts, embryo cultures and pollen among the International Coconut Genebanks (ICGs) of the International Coconut Genetic Resources Network (COGENT), and between the ICGs and their country members.

The Pest Risk Analysis process

Phase 1: Initiating the PRA

Initiating the PRA process involves the identification of the range of pests that are likely to be in the pathway (carried by the propagule) such as seednuts, pollen or embryos. In the case of movement within and between the ICG centres, information on national pest status is taken from the available international technical literature. International pest data can be taken from sources such as the FAO/IPGRI Guidelines for the exchange of coconut germplasm (Frison *et al*. 1993), the CABI Crop Protection Compendium (CABI 2003) and other sources. Such a literature search initially compiles information on all pests associated with the coconut crop worldwide, irrespective of the type of material that is to be moved as germplasm. Therefore, this primary information gathering activity is non-selective but forms the basis for decision-making.

Crucial to the correct progression of the PRA process is the determination of the pest status of the respective countries in accordance with ISPM #8 Pest status in an area (FAO 1996b). In this case, the status of many pests is uncertain and, without conducting extensive in-country surveys, will have to rely upon the literature citations presently available. In the Asia Pacific region, there have been a number of useful compilations of pests and diseases of economic importance. These include data on the coconut crop, but these have been obtained in consultation with agencies that have not provided primary technical references as is generally the case of other compendia (APPPC 1987; Waterhouse 1993; Waterhouse 1997; Li *et al.* 1997). This information has been included at face value by CABI in its Compendium, but it has not been possible to further investigate the specific impact these pests have on the coconut palm, particularly the affected plant part, or to completely validate the records by further cross references. Therefore, it is essential that the relevant plant protection organization of a country verify the lists of pests compiled from literature sources with responsibility for research and extension in coconuts.

For each of the pests identified in the primary pest list, the technical data for pests of potential quarantine concern are compiled in a pest datasheet. The data compiled include information on pest biology, in particular that which relates to the capacity of the pest to be in the pathway and to enter, establish and spread in the importing area. When available, information on the economic importance of the pest is also gathered in order to support the classification of the pest as a quarantine pest in accordance with the International Plant Protection Convention's definition of a 'quarantine pest' and Phase 2 of the PRA process.

At the end of this first phase of the PRA process, a list of pests in the country of export is compiled together with a list of pests in the importing country. By subtracting the second (importing) country list from the first (exporting) country list, a list of potential quarantine pests that move into Phase 2 of the procedure are determined.

Phase 2: Pest risk assessment

The second of final stage in the classification of the potential quarantine pests include those that would be in the pathway for tissue cultured embryos, seednuts or pollen and is undertaken as the final component of the completion of the datasheet for each pest. The assumptions made concerning economic impact are included in this classification.

In each datasheet, the quarantine status for exchange of seednuts, embryo culture and pollen is also recorded.

For each quarantine pest or pest of potential quarantine threat, on each datasheet, an assessment of the risk of the pest in each of the three pathways is made using the following table:

Key biological information	PRA*		
	Seednuts	Embryo culture	Pollen
Risk of entry			
Risk of establishment			
Risk of spread			
Economic impact			
Quarantine status			
Overall risk			
Risk management required			

***Legend**: *L=low M=medium H= high NA=not applicable*
Y=yes N= no
Q=quarantine pest NR= non-regulated pest

Pests that are recorded as being associated with coconut growing but are not on the germplasm pathway such as larger mammals (vertebrates), nematodes and weeds are eliminated from the analysis for the following reasons:

Vertebrate pests

Rats (*Rattus* sp) and the plantain squirrel (*Callsciurus notatus*) are too large to be in any pathway considered for germplasm exchange.

Nematodes

Nematodes can be serious pests of coconuts, but are root pests and would not be in the pathway and are not considered further in this analysis. If nuts were harvested from the ground and could be contaminated with soil, nematodes could be in the pathway.

Weeds

A large number of weed species are recorded in association with the cultivation of coconuts as an economic crop. Many are economically significant. However, none would be considered in the pathway, as it would be expected that only seednuts from the palm would be used for germplasm exchange and they would be cleaned of any material prior to partial de-husking. Weeds would only be a problem if nuts were harvested from the ground and could be contaminated with soil.

Arthropod pests

Seednuts. Leaf and trunk pests are not considered to pose a serious risk with the import of nuts. A number of pests are recorded on flower heads and young nuts and are considered in the pathway. A number of general pests such as scales and mites are found on all parts of the coconut plant and have been considered as hitchhikers. These pests will require risk management options.

Embryo cultures. Arthropod pests are not considered to enter the pathway for imports that are made as embryo cultured material because of the technique that is used and the sterile conditions under which the material is extracted and cultured.

Pollen. A number of pests infest the floral parts of the coconut such as *Tirathaba rufivena* and *Unaspis citri* and could be a problem if care is not taken during harvest. However, they are large enough to be able to be detected by visual inspection.

Mites are sometimes a problem with contamination of pollen harvested in the field, and would require examination using a hand lens or binocular microscope to detect infestation.

Diseases

Seednuts. Pests are only considered of quarantine significance if they are known to be seed borne, such as *Marasmius palmivorus* (oil palm bunch rot). Many pests are systemic but not seed transmitted such as Foliar decay and *Anomola pallida*.

Embryo cultures. Pests that are systemic may not necessarily be present in the embryo. However, one pathogen cadang-cadang, has been detected in the embryo, but is not proven to be seed borne.

Pollen. Most pests do not infect pollen although cadang-cadang has been detected in pollen. Whether it is pollen borne is not proven.

Diseases and pests of unknown etiology
Frison *et al.* (1993) lists a number of diseases/disorders of unknown etiology that are present in Asia and the Pacific regions. Those included are Finschhafen disease, Frond rot, Malaysia wilt, Natuna wilt, Socorro wilt and Stem necrosis.

These diseases are restricted in distribution and the precautionary principle is implemented by requiring that material of all types moved from areas where they occur should be from areas free of the pests in accordance with international standards for pest free areas (ISPM # 4 FAO 1996b). Since the causes of the diseases are not known since no tests are available, this is the only phytosanitary management option.

In accordance with ISPM #2 at the end of Phase 2 of the PRA process, the quarantine pests in the pathways should have been identified. These pests would now require that phytosanitary management procedures be identified to address the phytosanitary risk identified.

Phase 3: Pest risk management
It is assumed that all COGENT ICGs have the capacity to handle germplasm as seednuts, tissue cultures and pollen, and that they have the equipment to undertake the risk management operational procedures that are recommended. If the genebanks do not have the capability to undertake the required treatments then they must be undertaken before export at the point of exit or if post entry quarantine is not possible, then third country, intermediate quarantine would be required. Management options for the movement of germplasm between the Asian and Pacific COGENT ICGs in India, Indonesia and Papua New Guinea are given in Annex 1.

Management of quarantine pest groups
Although a number of different pests have been identified as quarantine pests in Annex 1, these need not be dealt with on an individual basis. Quarantine pests management strategies are developed to deal with the risks of pest groups of 'like minded' pests, rather than individual quarantine pests.

Arthropod pests
Seednuts. The accepted method of managing arthropod pests has been fumigation with an appropriate broad-spectrum chemical (Frison *et al*. 1993). Currently, the practice is to remove part of the husk of the coconut, thereby removing some of the pests, and to fumigate with methyl bromide (MeBr) at the rate of 32g per cubic metre for three hours at 21°C. This treatment will effectively deal with all arthropod pests that have casually

moved to the coconut fruit, such as the leaf feeders, scales, thrips, bugs and mites.

Methyl bromide is known to have some phytotoxic effect on coconuts and care should be exercised in undertaking the treatment. The treatment at 32g per cubic metre for 24 hours at 20°C is used for devitalisation treatment in Australia (treatment A7.b. in FAO 1984).Temperatures for the treatment should not be high, water should be placed in the chamber in trays before the fumigation begins to increase humidity. The dehusked nuts should be removed from the chamber as soon as the treatment is completed and placed in a cool, ventilated area to allow the fumigant to disperse from around the coir.

If MeBr is not available as a fumigant, then aluminium phosphide is an alternative at the rate of 225 ppm of phosphine gas for 120 hrs at 20°C (treatment B4h.(5)(e) in FAO 1984) or 2-3 tablets per cubic metre for 24-72 hours (treatment C13 (30) in FAO 1984).

Embryo cultures. Arthropod pests are not considered to be in the pathway when movement as tissue cultures is correctly undertaken. However, there have been instances where small mite pests have contaminated cultures, so imports should be carefully inspected for these pests on arrival by microscopic examination.

Pollen. Established methods for collecting pollen have been described (Balingasa and Santos 1978 and Frison *et al*. 1993). These methods would prevent pollen contamination from neighbouring palms and also prevent contamination by airborne pests if carefully applied.

Treatment of pollen is not possible, other than sieving out the larger contaminating pests, so all consignments should be carefully, visually inspected using a low power microscope, before dispatch and again at point of entry.

Fungal diseases

Seednuts. A number of fungal diseases have been recorded on seednuts and flower clusters and therefore have the potential to be in the pathway. Nevertheless, whether all of these are seedborne has not been determined, although the risk exists. Invoking the precautionary principle, it is recommended that where these diseases are identified by the PRA as of concern, the nuts should be grown in post-entry quarantine (PEQ). Where a disease occurs generally in an area, only healthy nuts should be selected for exchange. Where diseases are not widespread and do not occur in specific and defined areas, then nuts should be sourced from these pest free areas. Seednuts should be treated with an acceptable and registered fungicide before sowing in PEQ.

Embryo cultures. Embryo cultures free of contamination would not present a pathway for the introduction of fungal diseases.

Pollen. Pollen should be visually inspected after gathering for fungal spores and again at point of entry. Pollen found infected should be destroyed.

Viruses, viroids, mollicutes and phytoplasmas

These systemic diseases have to be managed either through sourcing from pest free areas, or by active testing where the disease occurs generally and is not controlled. The causal organism for some of these diseases has not been determined and the precautionary principle is invoked to ensure that risk of incursions with exchange is negligible.

As a general principle for these diseases, material should only be collected from palms showing no symptoms. Although this in no way guarantees freedom from these diseases, it does reduce the possibility of the disease being in the pathway.

Seednuts. They should never be moved directly from areas where non-cultivable mollicutes or *Phytomonas* occur, to areas not affected with these pathogens (Frison *et al*. 1993). This is recommended despite the fact that there is no firm evidence that any of these systemic diseases are transmitted by seed. The research on cadang-cadang in controlled non-infected areas has not been completed so material from the infected area should not be exchanged, or only made from palms indexed free of the viroid.

Embryo cultures. The presence of some systemic diseases has been detected in the embryo of coconuts. Therefore, material must only be taken from plants that are known to be free of these diseases, or the material taken as tissue must be indexed before release for growing in a propagation nursery.

Pollen. Cadang-cadang has been detected in pollen. However, the evidence of the disease being transmitted this way to seed is not yet available. Nevertheless, as a precautionary measure, pollen should be tested or sourced from areas free of cadang-cadang.

General phytosanitary measures for the movement of coconut germplasm

Administration (i.e., permits, etc.)

As well as compliance with countries' phytosanitary requirements, the collecting and exchange of germplasm should be undertaken with the full participation of the stakeholders, which could be collectors, breeders, other scientists and farmers. In the case of exchange between national and regional centres, it can be assumed that formal approval is sought for the movement at a bilateral level. Nevertheless, with the possibility of the movement from national sources outside the collections into other centres, compliance with good collecting practices should be iterated, particularly if a standard procedure is being developed and adopted worldwide, such as the International Code of Conduct for Plant Germplasm Collecting and Transfer.

This Code "aims to promote the rational collection and sustainable use of genetic resources, to prevent genetic erosion, and to protect the interests of both donors and collectors of germplasm. The Code, a voluntary one, has been developed by FAO and negotiated by its Member Nations through the Organization's Commission on Plant Genetic Resources. The Code is based on the principle of national sovereignty over plant genetic resources and sets out standards and principles to be observed by those countries and institutions that adhere to it. The Code proposes procedures to request and/or to issue licences for collecting missions, provides guidelines for collectors themselves, and extends responsibilities and obligations to the sponsors of missions, the curators of genebanks, and the users of genetic material"(FAO 1993).

The Code outlines the arrangements that should be made prior to collecting missions. In particular, import permits should be obtained that clearly indicate the phytosanitary conditions that must be met prior to the material being exported. With the increasing reliance on the concept of area freedom and the indexing of source plants, these phytosanitary requirements must be fulfilled otherwise, the material will most likely be destroyed on arrival.

Specifically the Code requires collectors or curators of collections to – "(c) make arrangements with quarantine officials, seed storage managers and curators to ensure that the samples are transferred as quickly as possible to conditions which optimize their viability; (d) obtain, in accordance with the importing countries' requirements, the phytosanitary certificate(s) and other documentation needed for transferring the material collected.

Treatments

Because of the uncertainty about the distribution of many of these pests and lack of precise information on their biology, particularly the parts of the plant affected, it is prudent to require a set of general measures to address overall pest risk as well as requirements for specific regulated pests. These general recommendations are as follows:

- Germplasm should only be collected from apparently healthy palms
- Seednuts should be collected from the palm, not from the ground
- Seednuts partially dehusked and fumigated at port of exit
- Seednuts be treated with an approved fungicide and grown in post-entry quarantine for at least one growing season (in the tropics, the duration of a wet season and at least three months of a dry season), for release only after examination and certification of pest freedom by a plant pathologist.

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Annex 1. Specific phytosanitary measures for the movement of coconut germplasm between and among the ICG host countries in the Asia and the Pacific regions (India, Indonesia and Papua New Guinea)

India to Indonesia

Quarantine Pests	Management Options		
	Nuts	Embryo	Pollen
Arthropods • *Coccus hesperidum* (brown soft scale) • *Nipaecoccus nipae* (spiked mealybug) • *Oligonychus biharensis* • *Raoiella indica* • *Tetranychus ludeni* (red spider mite)	Fumigation	Not applicable	Inspection
Diseases • *Hypocrea rufa* (fruit rot: *Citrus* spp.)	Fungicide and PEQ	Not applicable	Not applicable
• Kerala wilt (root wilt)	Area freedom*	Area freedom	Area freedom

Note: **Pest-free Area*

Indonesia to India

Quarantine Pests	Management Options		
	Nuts	Embryo	Pollen
Arthropods • *Hidari irava* (coconut skipper) • *Mahasena corbetti* (coconut case caterpillar) • *Rhabdoscelus obscurus* (New Guinea sugarcane weevil) • *Unaspis citri* (citrus snow scale)	Fumigation	Not applicable	Inspection
Disease • Natuna wilt	Area freedom	Area freedom	Area freedom

India to Papua New Guinea

Quarantine Pests	Management Options		
	Nuts	Embryo	Pollen
Arthropods • *Coccus hesperidum* (brown soft scale) • *Nipaecoccus nipae* (spiked mealybug) • *Oligonychus biharensis* • *Raoiella indica* Mites • *Tetranychus cinnabarinus* (carmine spider mite) • *Tetranychus ludeni* (red spider mite)	Fumigation	Not applicable	Inspection
Diseases • *Hypocrea rufa* (fruit rot: *Citrus* spp.)	Fungicide and PEQ	Not applicable	Not applicable
• Kerala wilt (root wilt)	Area freedom	Area freedom	Area freedom

Papua New Guinea to India

Quarantine Pests	Management Options		
	Nuts	Embryo	Pollen
Arthropods • *Amblypelta cocophaga* (coconut bug) • *Amblypelta theobromae* (coconut bug) • *Axiagastus cambelli* • *Mahasena corbetti* (coconut case caterpillar) • *Rhabdoscelus obscurus* (New Guinea sugarcane weevil) • *Unaspis citri* (citrus snow scale)	Fumigation	Not applicable	Not applicable
Diseases • *Phytophthora katsurae* (chestnut downy mildew)	Fungicide & PEQ	Not applicable	Not applicable
• Finschhafen disease	Area freedom	Area freedom	Area freedom

Indonesia to Papua New Guinea

Quarantine Pests	Management Options		
	Nuts	Embryo	Pollen
Arthropods • *Hidari irava* (coconut skipper) • *Icerya pulchra* • *Tetranychus cinnabarinus* (carmine spider mite)	Fumigation	Not applicable	Inspection
Disease • Natuna wilt	Area freedom	Area freedom	Area freedom

Papua New Guinea to Indonesia

Quarantine Pests	Management Options		
	Nuts	Embryo	Pollen
Arthropods • *Amblypelta cocophaga* (coconut bug) • *Amblypelta theobromae* (coconut bug) • *Axiagastus cambelli*	Fumigation	Not applicable	Inspection
Diseases • *Phytophthora katsurae* (chestnut downy mildew)	Fungicide and PEQ	Not applicable	Not applicable
• Finschhafen disease	Area freedom	Area freedom	Area freedom

Treatment recommendations

Fumigation: As recommended with methyl bromide (MeBr) or phosphine gas.

Dip: As recommended in Frison *et al*. (1993). The fungicide must be registered for use in particular circumstances and it is not therefore possible to make a specific recommendation here.

Post-entry quarantine: The nuts after treatment should be germinated in an enclosed area, preferably a greenhouse or a screenhouse depending on the capacity to control temperature. The plants should be grown for at least one growing season (in the tropics, the duration of a wet season and at least three months of a dry season) and during this time regularly examined by a qualified plant pathologist with experience in palm pathology. If required, samples of leaf and other material should be taken for specific diagnostic testing.

Diagnostic tests: Tests for specific disorders and diseases should be conducted as prescribed by Frison *et al*. (1993).

Area freedom: Some quarantine pests are not distributed throughout the country of origin of the germplasm. It is therefore possible to obtain certification from the national plant protection organization of the exporting country a declaration that the material (seednuts, embryo or pollen) have been obtained from an area where the specific pests of concern have not been detected. This declaration should be made on a Phytosanitary certificate that accompanies the consignment. If this is not obtained then testing must be done for the diseases, or if the risk is considered too great, then the material is destroyed.

Chapter 7

Information, public awareness, institutional support and partnerships

The international coconut genetic resources database

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Background

During the International Workshop on Coconut Genetic Resources, held in Cipanas (Indonesia) in October 1991, two major recommendations were made for coconut: the first was to set up the International Coconut Genetic Resources Network (COGENT), and the second, concerning network information and documentation, stated as follows:

"Participants agree on the need for a single central coconut database to be developed for the initial stage of the network. The offer by CIRAD Montpellier to act as a host for this database was gratefully accepted. […]"

A meeting was then organized in Montpellier (France) from 19 to 22 May 1992, with representatives from national collections to clarify the status of existing collections, define how the database was to be organized and draw up the list of descriptors to be taken into account, along with precise standardized ways of observing those descriptors. It was decided that the database would be developed in several stages. The development of an IT (Information Technology) application was initiated in 1992 with the presentation of a database mock-up called the Coconut Genetic Resources Database (CGRD), which eventually became the formal title for the database. It has continued since then on an annual basis.

Each stage involved adding/improving management system functionalities, and increasing the number of accession sites contained in the database. Furthermore, in order to take into account the progress made in IT techniques, the application, which initially functioned under the MS-DOS system, was completely rewritten for the Microsoft Windows system, so that photos and graphs could be displayed, and to provide a more user-friendly interface. Lastly, the progress made in molecular techniques, and their use on coconut to characterize genetic diversity, revealed the need to add the possibility of storing molecular information from these techniques in the database.

Table 1 shows how the database developed over the years in terms of its functions and content. It can be seen that the successive increases in the number of accessions over time has been irregular. The growth rates that can be calculated vary between 1 and 34%. From 1995 to 2002,

Table 1. Stages in the development of CGRD

Date	Version	Functions added/Improved	No. of accessions
1993	Mock-up	Passport data	0
	Version 1.0	Functions to query the database and to create reports	500
1994	Version 2.0	Characterization and evaluation data Backup function	669
1996	Version 2.1	DIP (Data Interchange Protocol) format for data export Restoration function	738
1997	Version 2.2	New structure Improved software	
1998	Version 2.2 improved	New DIP (Data Interchange Protocol) format for data export	936
1999	Version 2.2	New reports	1225
2000	Version 3.0 for Windows	Migration to Windows	
2001	Version 4.0 for Windows	Improved functions Export in delimited ASCII files (to use in statistical software)	1352
2002	Version 5.0 for Windows	Introduction of coconut molecular data	1369
2003	Version 5.1 for Windows	Improved backup function	1416

Brazil, China, India, Indonesia, Ivory Coast, Jamaica, Mexico, Papua New Guinea, Philippines, Sri Lanka, Thailand, Vanuatu and Vietnam (Bourdeix 1996; 1997a; 1997b; 1998; Bourdeix *et al*. 1999; Baudouin 2002) were visited and local researchers were trained in gathering and inputting data into the database. Such visits also provided an excellent opportunity to test the software in real situations and to detect items that needed improvements.

Objectives

The work on CGRD was initiated for the main purpose of providing the COGENT members with an easily consultable computerized catalogue of accessions representing a large number of cultivars spread throughout the coconut growing zone, in order to gain a clearer picture of coconut genetic diversity and thereby promote exchange of germplasm. This continues to be the main objective.

Another purpose of this database is for the COGENT country members to establish a list of passport descriptors and standardize characterization/assessment descriptors specific to coconut to be used by all partners. In addition, the database was created to speed up cultivar characterization and evaluation. The members of COGENT supplying the information contained in the database are regularly encouraged to add new information or complete the information already recorded requiring them to make a considerable effort to gather information and thereby improve their knowledge of the cultivars planted in their genebanks.

Organization

The data entered into the base are the values of passport and characterization descriptors for coconut accessions defined by COGENT. It also includes photos of the palms, along with results and diagrams from microsatellite molecular analyses. Based on an analysis of these data, and of the relations and constraints existing between them, a conceptual model of database organization was established. It provided a formal description of the database (Figure 1) using entities (symbolized by rectangles) corresponding to the natural objects identified in the system (sites, accessions, cultivars, photos, etc.), and relations (symbolized by circles) between those entities. This model was modified during development, when molecular data or photos were integrated.

In the model, accessions and cultivars form the core of the database. The database structure respects certain management rules, such as:

- It is compulsory for an accession to belong to a collection site and its number is unique in the database;
- A cultivar can be represented by several accessions; and
- Photographs and molecular data are attached to the cultivars.

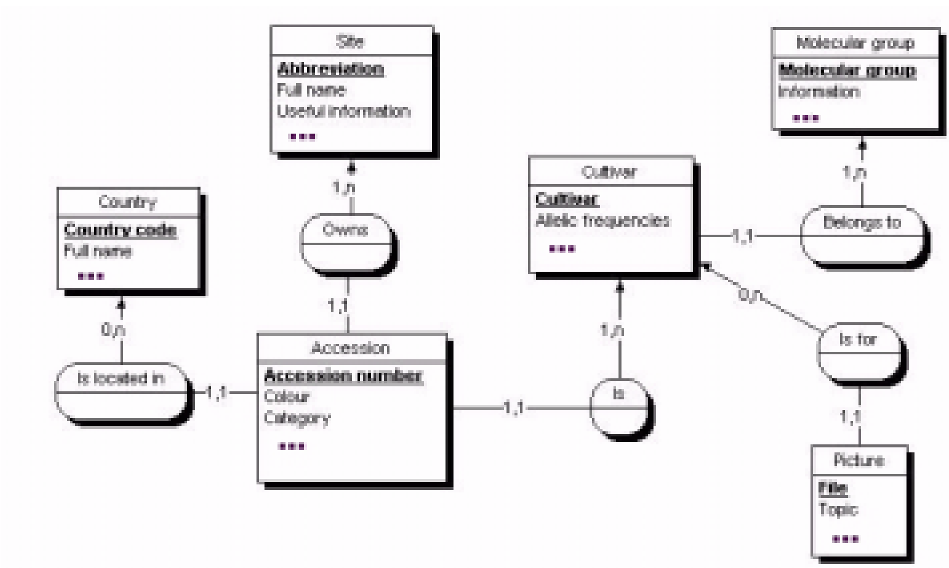


Figure 1. Simplified conceptual model of the CGRD

The conceptual model was translated into a relational type logical model (Figure 2) consisting of tables (symbolized by rectangles) linked to each other, derived from the entities and relations of the conceptual model. A relational type organization was chosen because it is a widely used organization, which has proven its worth and enables the use of a very powerful query language. Lastly, a very large number of commercial database management systems function with this type of organization. This logical model was implemented in the chosen relational database management system.

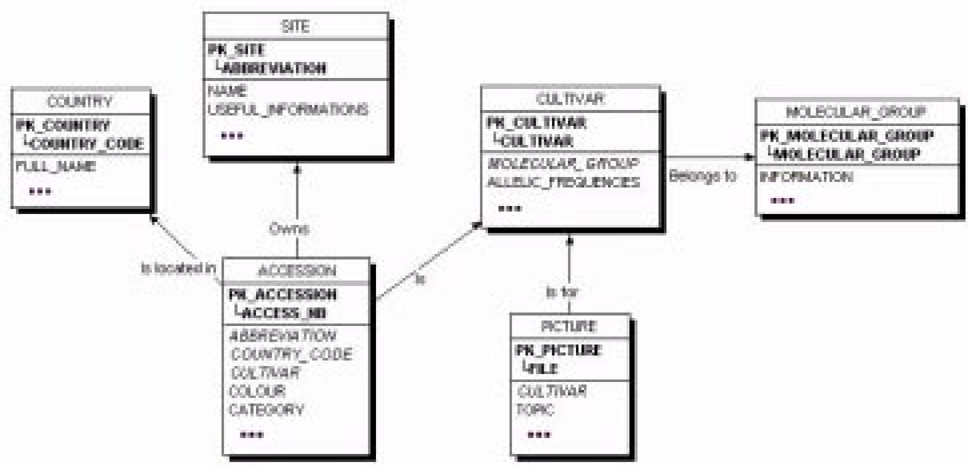


Figure 2. Simplified relational logical model of CGRD database

The CGRD was designed to function in a semi-centralized way. All COGENT members have a version of the database on their machine, which can be used to consult the entire catalogue, and to add or update data on the accessions at their site. In the latter case, a basic functionality enables data backup per site, for transmission to CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), the organization that centralizes the data from all the collection sites. CIRAD checks data coherence before entering them in the database, which is distributed annually to COGENT members.

Functions

The CGRD has a management system endowed with functions that can be used to carry out all the necessary operations on the data it contains. Among the functions available, which are listed below, there are those that are found in conventional database management systems, but there are also specific functions, given the nature of the database:

- Entering/consulting information on collection sites
- Entering/consulting data on individual accessions
- Selections in the database using criteria
- Creation of various types of reports

- Backing up of the database on an external medium
- Restoring database from a previous backup to the computer hard disk (when the database files are damaged on the hard disk)
- Exporting accession data in D.I.P. format (Data Interchange Protocol, for introduction into generalized genetic resources databases accepting this format)
- Consulting pictures of coconut cultivars on various topics
- Consulting the molecular group-based coconut classification
- Obtaining information on microsatellite markers and viewing the electrophoretic profile
- Online help

The database has a Microsoft Windows type graphic interface with a menu from which operations to be implemented on the data can be chosen.

Figures 3 to 5 show how data are displayed in CGRD. The screen displayed in Figure 3 is a part of the main screen of CGRD where pictures can be seen and from which descriptors data can be entered by clicking on the Passport or Characterization and evaluation data tabs.

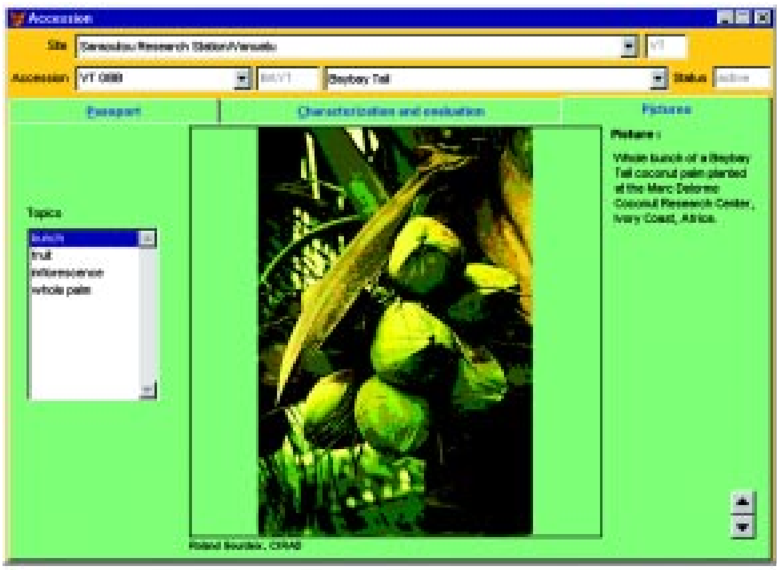
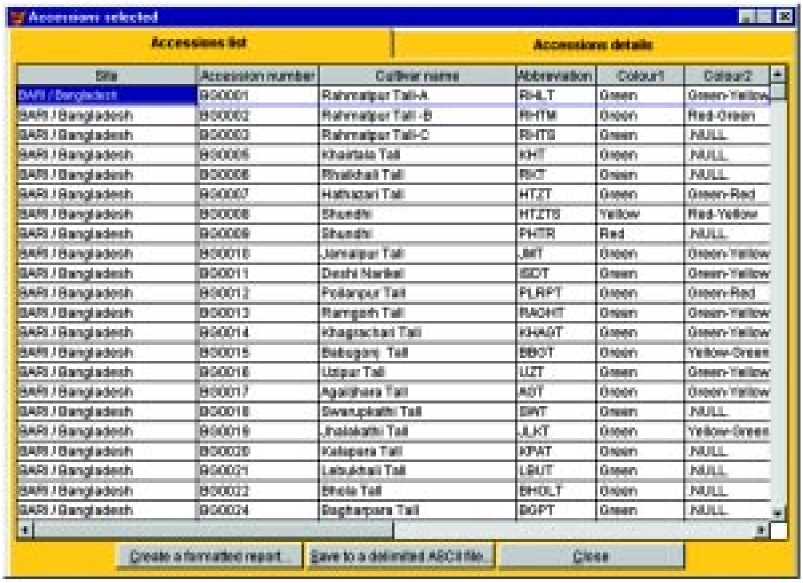


Figure 3. The tab picture of the accession screen in CGRD

Figure 4 shows a list of accessions retrieved after a successful search in the database. By clicking on the Accessions details tab when an accession is selected, all previously entered information on passport or on characterization data will be displayed on the screen.



Accessions selected

Accessions list | Accessions details

Site	Accession number	Cultivar name	Abbreviation	Colour1	Colour2
BARI / Bangladesh	BGD0001	Rahmatpur Tall-A	RHLT	Green	Green-Yellow
BARI / Bangladesh	BGD0002	Rahmatpur Tall -B	RHTM	Green	Red-Green
BARI / Bangladesh	BGD0003	Rahmatpur Tall-C	RHTG	Green	NULL
BARI / Bangladesh	BGD0005	Khairtala Tall	KHT	Green	NULL
BARI / Bangladesh	BGD0006	Rhakhali Tall	RKT	Green	NULL
BARI / Bangladesh	BGD0007	Hathazari Tall	HTZT	Green	Green-Red
BARI / Bangladesh	BGD0008	Shundhi	HTZTS	Yellow	Red-Yellow
BARI / Bangladesh	BGD0009	Shundhi	PHTR	Red	NULL
BARI / Bangladesh	BGD0010	Jamalpur Tall	JMT	Green	Green-Yellow
BARI / Bangladesh	BGD0011	Deshi Narikel	SDT	Green	Green-Yellow
BARI / Bangladesh	BGD0012	Pollanpur Tall	PLRPT	Green	Green-Red
BARI / Bangladesh	BGD0013	Ramgarh Tall	RAGHT	Green	Green-Yellow
BARI / Bangladesh	BGD0014	Khagrachari Tall	KHAGT	Green	Green-Yellow
BARI / Bangladesh	BGD0015	Babuganj Tall	BBGT	Green	Yellow-Green
BARI / Bangladesh	BGD0016	Uzipur Tall	UZT	Green	Green-Yellow
BARI / Bangladesh	BGD0017	Agailjhara Tall	AGT	Green	Green-Yellow
BARI / Bangladesh	BGD0018	Swarupkathi Tall	SWT	Green	NULL
BARI / Bangladesh	BGD0019	Jhalakathi Tall	JLKT	Green	Yellow-Green
BARI / Bangladesh	BGD0020	Kalapara Tall	KPAT	Green	NULL
BARI / Bangladesh	BGD0021	Lebukhali Tall	LBUT	Green	NULL
BARI / Bangladesh	BGD0022	Bhola Tall	BHOLT	Green	NULL
BARI / Bangladesh	BGD0024	Bagharpara Tall	BGPT	Green	NULL

Create a formatted report... | Save to a delimited ASCII file... | Close

Figure 4. The screen resulting from a successful selection of accessions in CGRD

Figure 5 shows the Classification Tree of the coconut cultivars annotated with the molecular groups identified in the species. A click on a letter of the molecular group, displays the list of cultivars of the same group on the right of the screen.

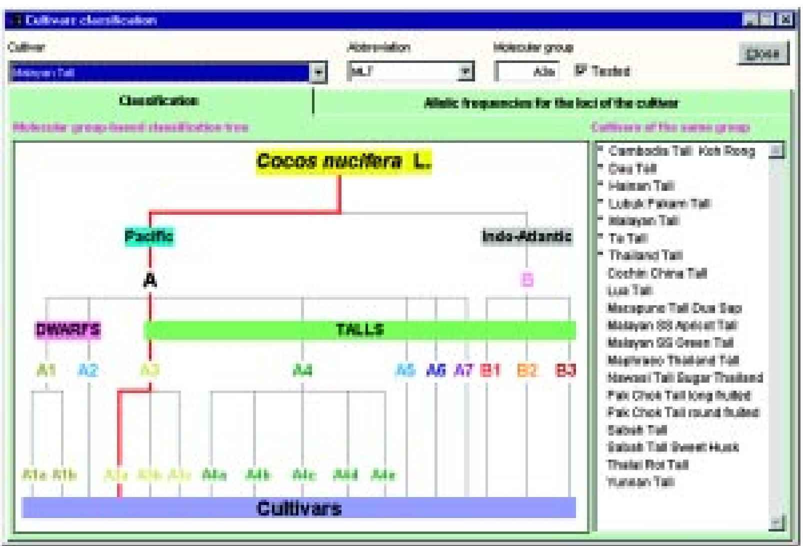


Figure 5. The Classification Tree in CGRD

Contents

Each accession in the database is characterized by 145 descriptors, of which there are 72 passport descriptors and 73 characterization and evaluation descriptors. Passport descriptors are divided into two groups: the accession data group, which contains accession characteristics (category, colour, cultivar, parental origin, etc.) and the collection data group, which contains data on the site and the original population from which the accession was sampled.

The characterization and evaluation descriptors are generally quantitative traits, whose values are means, calculated from values measured on several palms. A standard deviation is associated with each of the means, to have an idea of the variability of the trait within the accessions. To obtain these values, a data management system has to be put in place for every palm in the field. This is not trouble-free, because it has to be carried out over a long period following a regular schedule. In order to help researchers to follow this management protocol, COGENT has committed CIRAD in 1996 to develop dedicated software called CDM (Coconut Data Management). This software was designed to manage experimental data observed on collections and experimental fields of coconut and other crops. The version 3 delivered in March 2000 is able to manage the palm identification characters along with data on observations during the vegetative phase, leaf morphology, stem measurements and state of the palms. It is possible to execute powerful queries on the database, to export data into external file, and to make statistical analysis of widely used experimental designs.

The CGRD characterization and evaluation descriptors are divided into:

- Site descriptors, information about the site at which the accession is to be found and about the people assessing it;
- Germination descriptors, germination rates and percentages;
- Stem descriptors, stem morphology (height, circumference, number of internodes, etc.);
- Leaf descriptors, leaf morphology (petiole, rachis, leaflets, etc.);
- Inflorescence descriptors, to characterize inflorescences (peduncle, spikelets, number of female flowers, etc.);
- Flowering descriptors, such as the length of male and female phases, information on overlapping of these phases, spathe emission date, inflorescence opening date, etc.;
- Fruit descriptors, nut characteristics (shape, weight of different compartments, dry matter weight, etc.);
- Yield descriptors, number of bunches, number of nuts, quantity of copra; and

- Oil descriptors, oil/nut characteristics (quantity of oil in fresh matter and in dry matter form).

In 2003, the main statistics about the database were as follows (Table 2a and 2b):

- The accessions of 28 genebanks located in South Asia, Southeast Asia, the South Pacific, Africa, and the Caribbean–Central America zone figure in the database.
- Some countries, such as Indonesia, Malaysia and Papua New Guinea, have at least two sites where collections are maintained, with a maximum of four for Indonesia.
- A little over 60% of the accessions are in the South and Southeast Asia, primarily in India, the Philippines and Indonesia.
- Not all the descriptors are filled in; a little over half of the accessions (all sites combined) have values for 25% to 50% of their passport and evaluation descriptors.
- Very few accessions have values for 100% of their passport descriptors or evaluation descriptors.
- The database lists 599 Tall cultivars, 111 Dwarf cultivars, 1 semi-Tall cultivar plus a few others of small size but cross-fertilizing.
- Some cultivars such as the Malayan Tall, Pakistan Tall are described very often in the database, represented by 49 and 32 accessions, respectively, whereas more than 70% of the cultivars are only represented by one accession.
- The database contains 754 photos representing a little over 20% of the cultivars. The aspects illustrated are the whole plant, the crown, the inflorescence, the fruit, genetic diversity, and cultural aspects of the coconut palm.
- Photos of inflorescence, bunch and fruit are the most numerous.
- The molecular data contained in the database come from microsatellite electrophoresis studies carried out on cultivars. On average, 14 microsatellite loci have been analyzed per cultivar.
- For each cultivar and each locus, the frequencies of the different alleles found at the locus are indicated.
- Based on the allelic frequencies of the microsatellite loci studied, cultivars have been assigned to different molecular affiliation groups. The molecular group of each cultivar is also recorded in the database.

A cultivar classification tree based on the molecular groups is proposed in one of the database modules. It is possible to move along the different branches of the tree, bringing up a list of the cultivars attached to the selected molecular group in each case. The microsatellite data of 119 cultivars are stored in the database. Lastly, data per microsatellite locus (SSR locus type, allele size, number of alleles, chromosome etc.), along with images of the microsatellite electrophoretic profiles and profile interpretation diagrams are also recorded in the database.

Table 2a. Number of accessions per site or per region according to the percentage of passport descriptors (P) filled in

Site	Number of accessions	P=0	0<P≤25	25<P≤50	50<P≤75	75≤P≤100
CNRA Marc Delorme Research Station, Côte d'Ivoire	99	0	0	28		7
Coconut Programme, OPRI, Ghana	16	0	16	0	0	0
CRC Sémé Podji, Benin	4	0	0	4	0	0
National Coconut Development Programme, Tanzania	72	0	1	63	8	0
AFRICAN REGION	**191**	**0**	**17**	**95**	**72**	**7**
Centro de Investigacion Cientifica de Yucatan, Mexico	20	0	0	20	0	0
Coconut Industry Board, Jamaica	60	0	44	15	1	0
EMBRAPA, Brazil	16	0	0	0	16	0
LATIN AMERICA-CARIBBEAN REGION	**96**	**0**	**44**	**35**	**17**	**0**
BARI, Bangladesh	40	0	22	16	2	0
Coconut Research Institute, Sri Lanka	78	0	0	46	32	0
CPCRI, India	212	0	71	74	67	0
RS, Pakistan	32	0	32	0	0	0
SOUTH ASIAN REGION	**362**	**0**	**125**	**136**	**101**	**0**
Cocoa and Coconut Research Institute, PNG	3	0	3	0	0	0
Ministry of Agriculture, Tonga	7	0	7	0	0	0
Saraoutou Research Station, Vanuatu	79	0	6	26	45	2
Stewart Research Station, PNG	54	0	23	31	0	0
Taveuni Coconut Centre, Fiji	11	0	2	0	8	1
RS, Western Samoa	9	0	9	0	0	0
RS, Yandina, Solomon Islands	21	0	17	4	0	0
SOUTH PACIFIC REGION	**184**	**0**	**67**	**61**	**53**	**3**
RS, China	17	0	2	15	0	0
Department of Agriculture, Sabah, Malaysia	45	0	22	23	0	0
MARDI, Hilir, Perak, Malaysia	44	0	10	34	0	0
Bone Bone Experimental Garden, S. Sulawesi, Indonesia	41	0	6	35	0	0
Mapanget Experimental Garden, N. Sulawesi, Indonesia	74	0	0	63	11	0
Pakuwon Experimental Garden, W. Java, Indonesia	25	0	3	21	1	0
Sikijang Experimental Garden, Indonesia	30	0	0	10	20	0
Philippine Coconut Authority, Philippines	224	0	3	220	1	0
Chumphon Horticultural Research Centre, Thailand	52	0	10	37	5	0
Dong Go Experimental Center, Vietnam	31	0	0	1	29	1
SOUTHEAST ASIAN REGION	**583**	**0**	**56**	**459**	**67**	**1**
TOTAL FOR ALL REGIONS	**1416**	**0**	**309**	**786**	**310**	**11**

Table 2b. Number of accessions per site or per region according to the percentage of evaluation descriptors (E) filled in

Site	Number of accessions	E=0	0<E≤25	25<E≤50	50<E≤75	75≤E≤100
CNRA Marc Delorme Research Station, Côte d'Ivoire	99	0	28	28	43	0
Coconut Programme, OPRI, Ghana	16	12	0	4	0	0
CRC Sémé Podji, LOCATION Benin	4	0	0	4	0	0
National Coconut Development Programme, Tanzania	72	0	3	69	0	0
AFRICAN REGION	**191**	**12**	**31**	**105**	**43**	**0**
Centro de Investigacion Cientifica de Yucatan, Mexico	20	0	19	1	0	0
Coconut Industry Board, Jamaica	60	0	2	58	0	0
EMBRAPA, Brazil	16	0	0	16	0	0
LATIN AMERICA-CARIBBEAN REGION	**96**	**0**	**21**	**75**	**0**	**0**
BARI, Bangladesh	40	0	3	3	34	0
Coconut Research Institute, Sri Lanka	78	0	14	51	13	0
CPCRI, India	212	0	1	138	73	0
RS, Pakistan	32	0	32	0	0	0
SOUTH ASIAN REGION	**362**	**0**	**50**	**192**	**120**	**0**
Cocoa and Coconut Research Institute, PNG	3	0	0	3	0	0
Ministry of Agriculture, Tonga	7	0	6	1	0	0
Saraoutou Research Station, Vanuatu	79	0	6	10	1	62
Stewart Research Station, PNG	54	0	0	54	0	0
Taveuni Coconut Centre, Fiji	11	0	4	3	4	0
RS, Western Samoa	9	0	0	9	0	0
RS Yandina, Solomon Islands	21	0	0	21	0	0
SOUTH PACIFIC REGION	**184**	**0**	**16**	**101**	**5**	**62**
RS, China	17	0	0	17	0	0
Department of Agriculture, Sabah Malaysia	45	0	15	30	0	0
MARDI Hilir Perak, Malaysia	44	0	5	2	37	0
Bone Bone Experimental Garden, S. Sulawesi, Indonesia	41	0	0	41	0	0
Mapanget Experimental Garden, N. Sulawesi, Indonesia	74	0	29	45	0	0
Pakuwon Experimental Garden, W. Java, Indonesia	25	0	0	25	0	0
Sikijang Experimental Garden, Indonesia	30	0	0	30	0	0
Philippine Coconut Authority, Philippines	224	0	5	138	81	0
Chumphon Hort. Research Centre, Thailand	52	0	0	52	0	0
Dong Go Experimental Center, /Vietnam	31	0	15	12	4	0
SOUTHEAST ASIAN REGION	**583**	**0**	**69**	**392**	**122**	**0**
TOTAL FOR ALL REGIONS	**1416**	**12**	**187**	**865**	**290**	**62**

Technical references

The CGRD management system for the relational structure is Microsoft Visual FoxPro software, which operates under Microsoft Windows. Tables are in Dbase (DBF) format, which is a universally recognized format.

Conclusion

The CGRD is a very useful tool for coconut genetic resources management, and can help planting material exchanges. It can be considered that the development of the database is now mostly complete. However, extra outputs for dedicated software such as the new geographical information system DIVA-GIS, which is tailor-made for genetic resources, should be included. It is also expected that the coconut descriptors list is a dynamic one and will evolve as new traits are added or the existing ones are modified. The CGRD has been designed to deal with such changes. For example, some morphological descriptors, such as the nut germ pore size and shape, may be added in the future. Moreover, the existing description of yield is often considered as insufficient by researchers. Similarly, the information about the pedigree of the accessions needs to be clarified and simplified in order for researchers to locate more easily the original collection site of the accessions.

Data for a large number of accessions on some of the descriptors is incomplete. Some key data, such as the inventory/counting of the living coconut palms, need to be updated much more often. It would also be worth adding photos, as too few varieties are illustrated. So far, molecular data have only involved microsatellite markers, but it is possible to add results from other types of molecular markers.

It is important to ensure that the number of accessions, photos and molecular data are increased significantly. This will have to be carried out by the national curators. Regular visits by technical experts to participating countries should be promoted to keep the momentum going and make the CGRD effort sustainable.

Lastly, it would be worthwhile if a version either complete or, only consultative, or even restricted to passport data of this database could be made accessible via the internet, as is the case for some other plants such as banana (Arnaud and Horry 1997). This would greatly help the global collaborative effort on coconut genetic resources conservation and their utilization. But this would require cooperation and agreement of the COGENT member countries.

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Public awareness initiatives in coconut

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> *"... **public awareness** is critical for promoting sustainable development and improving the capacity of the people to address environment and development issues. It is also critical for achieving environmental and ethical awareness, values and attitudes, skills and behaviour consistent with sustainable development and for effective public participation in decision-making."*
>
> *- **Agenda 21, Chapter 36.3***

Introduction

In recent years, various factors have led scientists and development workers to recognize the need to convince people outside their field of the value of their work. These factors include the world's growing development challenges, the revolutionary potential of information to bring about large-scale change, and greater competition for fewer resources.

In particular, the remarkable growth of the Internet over the past decade has transformed us from a society of one-way information providers into a society of communicators that is based on open debate and transparency. At the same time, as the lines between national, regional and international development concerns have started to blur, there have been greater incentives to seek common approaches to global problems. Multilateral approaches to problem-solving are terrifically complex — not to mention expensive — hence the need for broad popular support for development activities is particularly important.

Most recent international agreements concerned with agriculture and the environment stress the important role that can be played by public awareness in the promotion of sustainable development. Agenda 21 devotes an entire chapter to the subject. The Convention on Biological Diversity also emphasizes the importance of public awareness. More recently, the Global Plan of Action for plant genetic resources, adopted in Leipzig, Germany in 1996 by 160 countries, identified public awareness as one of its 20 priority activities.

Public awareness (PA) is an important tool for mobilizing popular opinion and for generating and sustaining action and political and funding support within countries and globally. A targeted PA programme can promote the development of international linkages and collaborative mechanisms. Within the International Coconut Genetic Resources Network's (COGENT) member countries, public awareness can facilitate efforts to involve communities and local and non-governmental organizations in coconut genetic resources activities, thus ensuring a broader base for conservation (Stapleton *et al.* 2004).

COGENT's public awareness strategy

COGENT's overarching public awareness goal is the promotion of the collecting, conservation and use of coconut genetic resources. To achieve this goal, the network developed its own PA strategy in line with the International Plant Genetic Resources Institute's (IPGRI) general PA mandate, targeted towards specific audiences. The following matrix table summarizes COGENT's PA strategy and related tools/ methodologies.

Table 1. Matrix summary of COGENT's public awareness strategy and methodology

PA Goals and specific objectives	Target audience	Methods/Tools of information dissemination
Promote collecting of coconut germplasm: • Strengthen the research capacity of national and regional programmes; • Establish and maintain the multi-site International Coconut Genebank (ICG) to collect and conserve coconut genetic resources; and • Identify suitable varieties/hybrids for yield improvement and enhanced adaptation	Policy makers/ government officials	• Newspaper articles • COGENT Newsletter • COGENT Secretariat-produced publications/ books (selected) • Brochures/ pamphlets/ flyers • Factsheets • Internet (COGENT webpage)
	Donors	• Newspaper articles (selected) • COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Brochures/ pamphlets/ flyers • Factsheets • Project/progress reports • Internet (COGENT webpage)
	Scientists/ researchers	• COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Project/progress reports • Journals and flyers • Internet (COGENT webpage) • CD-ROM and databases
	Coconut breeders	• COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Project/progress reports • Journals and flyers • Internet (COGENT webpage) • CD-ROM and databases

PA Goals and specific objectives	Target audience	Methods/Tools of information dissemination
Promote the conservation of coconut genetic resources: • Develop and strengthen collaboration between and among coconut-producing countries and partner institutions in the conservation and use of coconut genetic resources; • Refine embryo culture and acclimatization techniques; • Encourage the *in* situ and on-farm conservation of coconut genetic resources through better cultivars, increased yields and increased coconut-based farm incomes; and • Identify suitable varieties/hybrids for yield improvement and enhanced adaptation	Policy makers/ government officials	• Newspaper articles • COGENT Newsletter • COGENT Secretariat-produced publications/ books (selected) • Brochures/ pamphlets/ flyers • Factsheets • Internet (COGENT webpage) • Mass media (television/ radio)
	Donors	• Newspaper articles (selected) • COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Brochures/ pamphlets/ flyers • Factsheets • Project/progress reports • Internet (COGENT webpage)
	Scientists/ researchers	• COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Project/progress reports • Journals and flyers • Internet (COGENT webpage) • CD-ROM and databases
	Coconut breeders	• COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Project/progress reports • Journals and flyers • Internet (COGENT webpage) • CD-ROM and databases
	Partner institutions	• COGENT Newsletter • COGENT Secretariat-produced publications/ books • Project/ progress reports • Factsheets • Internet (COGENT webpage)
	Coconut product manufacturers/ businessmen	• Newspaper articles • Brochures/ pamphlets/ flyers • Posters • Internet (COGENT webpage) • Mass media (television/ radio)
	Coconut farmers and their households	• Newspaper articles • Illustrated brochures/ pamphlets/ flyers • Posters • Interactive/ hands-on demonstration • Mass media (television/ radio)

PA Goals and specific objectives	Target audience	Methods/Tools of information dissemination
Promote the use of coconut genetic resources: • Encourage increase in coconut production and utilization through the identification and production of high-value marketable alternative coconut-based products; • Conduct training courses on coconut genetic resources to strengthen human resources needs; and • Utilize results of research to promote socioeconomic and environmental benefits to resource-poor coconut farmers and coconut-producing countries	Policy makers/ government officials	• Newspaper articles • COGENT Newsletter • COGENT Secretariat-produced publications/ books (selected) • Brochures/ pamphlets/ flyers • Factsheets • Internet (COGENT webpage) • Mass media (television/ radio)
	Donors	• Newspaper articles (selected) • COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Brochures/ pamphlets/ flyers • Factsheets • Project/progress reports • Internet (COGENT webpage)
	Scientists/ researchers	• COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Project/progress reports • Journals and flyers • Internet (COGENT webpage) • CD-ROM and databases
	Coconut breeders	• COGENT Secretariat-produced publications/ books (selected) • COGENT Newsletter • Project/progress reports • Journals and flyers • Internet (COGENT webpage) • CD-ROM and databases
	Coconut product manufacturers/ businessmen	• Newspaper articles • Brochures/ pamphlets/ flyers • Posters • Internet (COGENT webpage) • Mass media (television/ radio)
	Coconut farmers and their households	• Newspaper articles • Illustrated brochures/ pamphlets/ flyers • Posters • Interactive/ hands-on demonstration • Mass media (television/ radio)

COGENT publications and other public awareness materials

In its effort to help disseminate strategies, technologies, and other information to promote coconut conservation and use, COGENT and IPGRI have produced and disseminated some 20 strategic publications and other public awareness materials (see list below). The network has also published eight issues of the COGENT Newsletter, including a special edition on the 'Poverty Reduction in Coconut Growing Communities' project, to serve as the main information medium for updating members about COGENT's current and future activities; as well as established and maintains the COGENT webpage (http://www.ipgri.cgiar.org/networks/cogent).

List and description of publications and other PA materials produced/co-produced by COGENT (1994-2005):

1. The International Coconut Genetic Resources Database (CGRD)

To equip member countries with relevant information and technologies for coconut research, COGENT, in collaboration with Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and with funding from the French Government from 1996 to 2003, developed the CGRD. To date, it contains the passport and characterization data (including some molecular marker data and pictures) of 1416 coconut accessions worldwide. CIRAD has incorporated in the CGRD and its associated software, a management system endowed with functions that can be used to carry out all the necessary operations on the data it contains. Individual countries can now update their database as they generate data from their genebank collections. This database helps coconut breeders to effectively select materials for developing improved varieties. For a more detailed discussion of the CGRD, please refer to the article entitled, 'International Coconut Genetic Resources Database' in this chapter.

2. Coconut breeding: Papers presented at a workshop on standardized techniques in coconut breeding (1992)

The papers were presented during the workshop on standardized techniques in coconut breeding (STANTECH) held on 20-25 June 1992 at CIRAD's Marc Delorme Research Station in Cote d'Ivoire. These discuss: (1) the origin and botany of coconut; (2) genetic variability and germplasm utilization; (3) current status and breeding efforts; (4) breeding strategies and methodologies; (5) varietal screening and utilization; (6) allied attributes; and (7) coconut biotechnology. These papers, along with others presented during the workshop, were compiled to form the 'Manula on standard tcehniques in coconut breeding' (see following item).

3. Manual on Standardized Research Techniques (STANTECH) in coconut breeding (1996)

The manual is the product of a workshop to standardize coconut breeding techniques organized by COGENT and held at the Marc Delorme Station of CIRAD in Cote d'Ivoire from 20 to 25 June 1992. During this workshop, coconut breeders from 16 coconut-producing countries and experts from IPGRI and CIRAD formulated the draft of the manual, which was later pre-tested and refined during the Trainers' Course on Coconut Breeding Research Techniques conducted at the Research Institute for Coconut and Palmae in Manado, Indonesia. The STANTECH Manual, as the publication has become known, enables coconut breeders and germplasm researchers worldwide to use standardized techniques as guidelines in breeding and germplasm conservation. This manual assists coconut researchers to obtain better and comparable results to accelerate the development of improved varieties for use by the coconut farmers.

4. Viroid-like sequences of coconut (1997)

This publication is the output of a workshop organized by the Australian Centre for International Agricultural Research (ACIAR), IPGRI and COGENT from 21-23 April 1997 in Kuala Lumpur, Malaysia to resolve the issue of viroid-like sequences in coconut. In this workshop, participants from laboratories in Australia, France, Italy and the Philippines presented summaries of their research and discussed the quarantine relevance of the viroid-like sequences in coconut. The participants also formulated research agenda to close apparent research gaps. The results of the workshop, including recommendations for treatment of coconut viroids and viroid-like sequences, are presented in this publication. It is envisioned that these recommendations will help open the way for the safe exchange and movement of coconut germplasm, while at the same time prevent the spread of pathogens.

5. Proceedings of the COGENT regional coconut genebank planning workshop, 26-28 February 1996, Pekanbaru, Riau, Indonesia (1998)

At the Steering Committee meetings of COGENT in 1992, 1993 and 1994, the network proposed the establishment of a multi-site International Coconut Genebank (ICG) and initially identify regional sites and its host countries: Southeast and East Asia (Indonesia), South Asia (India), South Pacific (Papua New Guinea) and Africa (Cote d'Ivoire). Task forces were created to evaluate the suitability of these sites. Based on the positive assessment and recommendation of the task forces, the COGENT Steering Committee proposed the holding of a Regional Coconut Genebank Planning Workshop to: (1) formulate guidelines for regional conservation of coconut genetic resources; (2) develop a 7-year workplan and budget for each of the four regional genebanks; (3) develop appropriate agreements between FAO, the host countries and IPGRI to govern germplasm acquisition, conservation and access; and (4) develop a sustainable funding strategy for the establishment and operation of these multi-site coconut germplasm collections. The workshop was conducted in Pekanbaru, Riau, Indonesia on 26-28 February 1996 and hosted by the Indonesian Agency for Agricultural Research and Development (AARD). This publication (proceedings) is the output of the said workshop and contains the following workshop documents: (1) background papers; (2) reports on evaluation of the host countries; (3) genebank guidelines, funding strategy and draft agreements; (4) proposed 7-year workplans and budgets; and (5) proposed (next) steps.

6. Coconut embryo* in vitro *culture (1998)
In an attempt to address the challenges in extending and implementing *in vitro* techniques and protocols for field collecting and embryo culture, especially in weaning or hardening of *in vitro* plantlets prior to field transplanting, COGENT, in collaboration with the Philippine Coconut Authority (PCA), conducted a workshop on *in vitro* culture of coconut embryo at PCA's Albay Research Centre (PCA-ARC) on 27-31 October 1997. This publication contains the papers presented during the workshop, which include: (1) the latest research results in coconut embryo culture and acclimatization of resulting plantlets; (2) bottlenecks and areas for improvement in coconut embryo *in vitro* culture; (3) research agenda for the next two years to address current difficulties; and (4) an optimized *in vitro* culture protocol which can be easily applied even by non-specialists.

7. Promoting multi-purpose uses and competitiveness of the coconut (1998)
This publication is the proceedings of a workshop organized by COGENT and held on 26-29 September 1996 in Chumphon, Thailand and hosted by the Chumphon Horticultural Research Centre of the Department of Agriculture, Thailand. It contains the findings of researchers and experts from 12 coconut-producing countries on new, high-value alternative uses of the coconut and high-profit coconut products. This proceeding is especially useful for researchers, coconut farmers and entrepreneurs to understand the opportunities that exist in producing high-value products from all parts of the coconut. It also contains examples of the many different types of products that can be made, ranging from food items, handicraft, toiletries and items for household use, as well as some 'low-

tech' methods for farmers to produce these items without heavy capital outlay for equipment and for material inputs.

8. Farmer participatory research on coconut diversity: Workshop report on methods and field protocols (1999)

As the title itself implies, this publication is a report containing the presentations, discussions and protocols produced at two simultaneous workshops on Farmer Participatory Research on Coconut Diversity, which were held on 16-28 March 1998 in Davao, Philippines and on 24-28 March 1998 in Taveuni, Fiji. These workshops were organized by IPGRI-COGENT and funded by the International Fund for Agricultural Development (IFAD) under the collaborative IPGRI-COGENT-IFAD project entitled, 'Sustainable uses of coconut genetic resources to enhance incomes and nutrition of smallholders in the Asia-Pacific region'. This publication is intended to serve as reference for coconut scientists and development workers in carrying out participatory field research with small-scale farmers, who are considered to be rich repositories of local knowledge on coconut diversity.

9. Coconut embryo* in vitro *culture: Part II (2002)

This publication is a follow up to the report entitled 'Coconut embryo *in vitro* culture' produced in 1998 (see item 5 above). Based on the research proposals submitted by the participants after the first International Workshop on Coconut *In Vitro* Culture held in Albay, Philippines in 1997, IPGRI-COGENT awarded projects to 12 researchers who conducted their studies from 1998 to 2001. These projects were funded by the Department for International Development (DFID) of the UK. The initial results of these research projects were reported during the 2nd International Workshop on Coconut *In Vitro* Culture, which was held in Merida, Mexico. These results are reported in this publication.

10. Performance of high-yielding coconut varieties/ hybrids and varietal preferences of coconut farmers in different countries (2002)

In 1998, the Asian and Pacific Community (APCC) organized an intra-regional study on small farmers' experiences with high-yielding coconut varieties. The objective was to assess the actual production potential of hybrids and their technical and commercial viability to small farmers. The study covered India, Indonesia, the Philippines, Sri Lanka, Thailand and Western Samoa. The findings highlighted the perception of farmers about the performance of coconut hybrids and exposing the limitations of coconut hybrids when grown under conditions different from that of experimental farms. After 1998, in light of the new hybrid combinations since released, as well as new techniques and methodologies in hybrid production and performance, APCC, in collaboration with BUROTROP and COGENT organized a follow up study entitled, 'Assessment of the performance of high-yielding coconut varieties/ hybrids and the varietal preferences of coconut farmers' , but this time covering the nine member countries of APCC as well as other coconut growing communities in Africa, Latin America and the Caribbean. The findings of this study are reported in this publication, which includes the adaptability, productivity, tolerance to biotic and abiotic stresses and suitability to farmers' conditions of hybrids in different agroclimatic conditions.

11. Poverty reduction in coconut growing communities: Volume I. The framework and project plan (2003)

This publication contains the project framework and individual country workplans and budget of the countries participating in the COGENT-coordinated, Asian Development Bank (ADB) - and IFAD-funded project entitled 'Poverty reduction in coconut growing communities'. This project involved 11 countries in the Asia-Pacific region, two in Africa and two in Latin America and the Caribbean. DFID funds were also committed as co-financing for the project. This publication is the result of the joint inception meeting for the ADB-funded project and stakeholder meeting for the project proposed for IFAD funding which was held in Ho Chi Minh City, Vietnam on 25 –28 February 2002 and subsequent interactions with implementing agencies and partner institutions.

12. Poverty reduction in coconut growing communities, Volume II: Mobilizing for action (2004)

This publication, which is the second in a series of three volumes related to the ADB-funded 'Poverty reduction in coconut growing communities' project, tries to briefly describe the major activities and processes before embarking on coconut-based income generating activity (IGA) trials and enhancing coconut genetic diversity through on-farm conservation and utilization. This publication may not be complete, but it can serve as a guide or reference for future similar projects of IPGRI or other organizations. Interested parties are encouraged to innovate, modify, adapt and be creative in their approach(es) depending on the sociocultural and political situations where they intend to implement similar projects. The preparatory activities include organizing project management team in every country (Bangladesh, Fiji, India, Indonesia, Papua New Guinea, Philippines, Sri Lanka and Vietnam) to manage field project implementation; selecting the project sites to pilot test the income generating technologies and strategies that will demonstrate that 'farmers need not be poor'; design and conduct of baseline data gathering to establish the status of the partner-beneficiaries and of the community, in general, so that changes or improvements can be measured towards the end of the project support; organizing farmers so that they can benefit from the strengths of one another and build their institutional capacity and confidence to play a major role in their community development and influence policy reforms; establishing microcredit system and revolving loan funds to provide opportunities to resource poor farmers and women to access capital to be used for their productive and entrepreneurial skills; market survey to identify the potential high-demand products to produce and develop market channels to attain maximum profits. From here, development of action plans by the farmers and women member of the CBO follows to focus on producing products they find profitable and of potential high market demand.

13. Poverty reduction in coconut growing communities, Volume III: Project achievements and impact (2005)
The final installation in a three-part series under the 'Poverty reduction in coconut growing communities' project, this publication documents the actual achievements of the project and its perceived initial impact on its farmer-beneficiaries through reports, articles and writeups substantiated by socioeconomic data and photos. Moreover, this book highlights the stories, experiences and testimonies of actual people – the communities, the farmers and their families, the country project implementers –attesting to what the project has achieved and how it affected and benefited their lives.

14. Germplasm health management for COGENT's multi-site International Coconut Genebank (2004)
COGENT had put in place a system that enables the network's 38 member countries to exchange valuable coconut germplasm through its multi-site International Coconut Genebank. Already, successful exchanges have been carried-out between the ICGs and the member countries. Taking a step further, COGENT has come out with this very useful and easy to understand manual on the basic procedures and guidelines to ensure the safe exchange of coconut germplasm. This manual, bringing together the combined experiences of well known germplasm health experts, outlines the basic procedures and approaches that coconut genebank managers could follow to effectively ensure the safe importing and exporting of coconut germplasm, as well as to provide a comprehensive reference for plant quarantine officers to make efficient and informed decisions for germplasm quarantine, specifically for coconuts.

15. Manual on technical writing, public awareness, seminar presentation and proposal preparation for coconut researchers (2004)
Activities and other initiatives related to the effective conservation and use of coconut genetic resources now and in the future need to be reported adequately and effectively to generate interest and support to coconut research. This publication will provide coconut researchers a guide on how to effectively write and present, in high-quality form, research activities, research results and proposals so that these could be better appreciated and supported by peers, research administrators, partner institutions, donors and the general public. In preparing the manual, the editors largely used materials in the IPGRI-organized workshops on technical writing held in Los Baños, Laguna, Philippines in September 1998 and in Hanoi, Vietnam in March 2002. It is also hoped that national programmes can use this manual to train coconut researchers to increase the cadre of effective scientific writers worldwide.

16. Coconut is good for your health: A multimedia CD-ROM (2005)
This multimedia VCD/ CD-ROM, which is a collaborative project of APCC, COGENT and the Philippine Coconut Authority (PCA), aims to promote the nutritional and health values of coconut and coconut-based products, as well as to dispel some notions about the negative effect of coconut on one's health. It contains documentation, anecdotes and personal interviews of health specialists attesting to the health benefits and positive effects of consuming coconut and its by-products, especially coconut virgin oil.

17. COGENT: Its history and achievements.* In *CORD Journal (2005)
Submitted and published in the CORD Journal of the APCC, this paper documents the history and achievements of COGENT, from its inception in 1992 up to the present.

18. Coconut hybrids for smallholders. Project reports and related papers of the multilocation trials to identify suitable coconut hybrids and varieties for Africa, Latin America and the Caribbean (2005)
To help small coconut farmers address some of the nagging problems they are facing such as decreasing farm productivity, low coconut yields and unstable markets of their traditional products, the Common Fund for Commodities (CFC) supported a project of COGENT/IPGRI from 14 December 1999 to 15 December 2004 entitled, 'Coconut Germplasm Utilization and Conservation to Promote Sustainable Coconut Production'. In this project, the performance of 34 promising coconut hybrids and varieties were tested in three African (Benin, Côte d'Ivoire, Tanzania) and three Latin American and Caribbean countries (Brazil,

Jamaica and Mexico).

This publication aims to help put into practical use the results of the project by enhancing awareness of the early-bearing and high-yield potential of the new developed hybrids in increasing yields and incomes of the poor coconut farmers.

***19. Coconut genetic resources* (this publication)**

The book documents current status and trends in coconut genetic resources conservation and utilization. It comprehensively covers a myriad of topics about coconut genetic resources and serves as one of the most authoritative reference material on coconut, whether for a layman or a researcher. Topics include: (1) an introduction to the coconut; (2) coconut germplasm collecting and conservation; (3) characterizing coconut diversity; (4) using coconut germplasm; (5) major pests and diseases of the coconut; (6) information and public awareness to promote conservation of coconut genetic resources; (7) institutional support and partnerships for coconut research and development; (8) reports on the status of coconut genetic resources in COGENT's sub-regional networks; and (9) reports on the status of coconut genetic resources in COGENT's 38 member countries.

***20. Coconut breeding.* In *Breeding plantation tree crops: Improving productivity and sustainability* (in press).**

This chapter in a book entitled, 'Breeding plantation tree crops: Improving productivity and sustainability'. It discusses the various aspects of coconut breeding, which includes: (1) the origin and botany of coconut; (2) genetic variability and germplasm utilization; (3) current status and breeding efforts; (4) breeding strategies and methodologies; (5) varietal screening and utilization; (6) allied attributes; and (7) coconut biotechnology.

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2. COGENT. October 1999. COGENT Newsletter, Issue No. 2. IPGRI-APO, Serdang, Selangor, Malaysia.
3. COGENT. May 2000. COGENT Newsletter, Issue No. 3. IPGRI-APO, Serdang, Selangor, Malaysia.
4. COGENT. November 2000. COGENT Newsletter, Issue No. 4. IPGRI-APO, Serdang, Selangor, Malaysia.
5. COGENT. March 2002. COGENT Newsletter, Issue No. 5. IPGRI-APO, Serdang, Selangor, Malaysia.
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APO, Serdang, Selangor, Malaysia.
7. COGENT. March 2003. COGENT Newsletter, Issue No. 7. IPGRI-APO, Serdang, Selangor, Malaysia.
8. COGENT. September 2004. COGENT Newsletter Special Edition (Poverty reduction in coconut growing communities). IPGRI-APO, Serdang, Selangor, Malaysia.

Proposed/ future publications (2006):
1. Coconut data analysis manual
2. Catalogue of coconut conserved germplasm and farmers' varieties (please see related article in this chapter for more details)
3. Catalogue of coconut high-value products (please see related article in this chapter for more details)
4. Catalogue of coconut food recipes (please see related article in this chapter for more details)

Public awareness under COGENT's 'Poverty reduction in coconut growing communities' project


Project brochures and newsletters being distributed to coconut farmers in Hung Phong commune, Vietnam

Public awareness (PA) is an important tool for mobilizing popular opinion, and for generating and sustaining action and political and funding support within countries and globally. A targeted public awareness programme can promote the development of national, regional and international linkages and collaborative mechanisms. It can facilitate efforts to involve communities, the local government and non-governmental organizations (NGOs) in coconut genetic resources conservation activities, thus ensuring a broader base for their effective use, particularly for poverty alleviation. Multilateral approaches to problem-solving are very complex - not to mention expensive – hence, the need for broad popular support for development activities is particularly important (Stapleton, *et al.* 2004).

The PA strategy of COGENT under its 'Poverty reduction in coconut growing communities' (PRCGC) project has the specific objectives of: (1) promoting a better understanding of the importance of coconut genetic

Farmers' field days provided the venue and the opportunity for participating farmers and CBOs to exhibit their products and show other project stakeholders their achievements. This also provided the impetus for local governments to further support the activities of the project communities

resources among policy-makers in reducing poverty; (2) swaying public opinion to positively influence the stakeholders' concern and action to support coconut genetic resources research, conservation and utilization; (3) creating a common forum for partners and collaborators to catalyze sustainable popular and broad-based support to the operational activities of the project; and (4) priming national partners into replicating the project in more sites in their respective countries and adopting its strategy and framework into their national development (poverty alleviation) programmes.

Output-wise, the eight PRCGC project participating countries (Bangladesh, India, Sri Lanka, Indonesia, Philippines, Vietnam, Fiji and Papua New Guinea) have produced a number of PA materials and have conducted numerous PA activities (Table 1). Since the start of the project in 2002, the community-based organizations (CBOs) of the 25 pilot sites, with the help of their respective country implementing agencies, have produced 140 public awareness materials comprising of popular articles in local and national newspapers, agricultural magazines, technoguides, books and scientific journals. Furthermore, 54 farmers' field days (i.e., six to seven per participating country) have also been conducted by the CBOs in the communities to showcase the achievements of the farmer- and women-participants of

During the project, events like field visits and field days were usually covered by the local media. This provided the opportunity for the project implementers to widely publicize the activities and outputs of the CBOs. Here, Dr Pons Batugal, Project Coordinator, is shown being interviewed by PacificTV, a local television station in Wori, Indonesia the project. The local broadcast media, particularly in Vietnam, Indonesia and India, covered some of these field days. Representative staffs of the implementing agencies have also made presentations about the project in national and international conferences and meetings. The communities themselves have also participated in product exhibitions, just like in the Philippines during the National Coconut Week celebrations sponsored by the Philippine Coconut Authority. To exemplify the initial impact of the project on the lives of the household beneficiaries,128 success stories have been documented and generated from the 24 project communities in the eight participating countries.

With an effective PA strategy, COGENT was able to generate technical and financial support for the project, especially in the regional and international arenas. The external resources generated by COGENT enabled its Secretariat to contract experts in various coconut-based income-generating technologies, resulting in the production of 14 training manuals that have been distributed to the participating communities. These manuals were condensed and translated into the local language by some of the country implementing agencies and given to the CBOs. Additionally, the network has produced a three-volume series of publications on the PRCGC project: Volume I: The Framework and Project Plan, which documents the framework of the project as well as the country workplans and budgets; Volume II: Mobilizing for Action, which which contains the capacity building-related activities to prepare the project participants undertake income-generating activities; and Volume III: Project Achievements and Impact, the final instalment in the series, which features the accomplishments and initial impact the project has achieved in the participating countries. This publication also contains 128 success stories as documented in the project sites. These publications aim to provide an over-all perspective of the project, as well as provide insights and lessons to people and institutions interested to undertake or support a similar project (Batugal and Oliver 2005).

Table 1. Summary table of PA materials produced and farmers' field days conducted, by project participating country

Country	Number of PA materials produced and PA activities conducted*	Number of farmer field days conducted
Bangladesh	14	7
India	63	7
Sri Lanka	7	7
Philippines	26	7
Indonesia	5	7
Vietnam	17	7
Fiji	5	6
Papua New Guinea	3	6
TOTAL for all countries	**140**	**54**

**including media (TV and radio) coverage*

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Public awareness initiatives in coconut

Standardized catalogues of coconut germplasm: Catalogue of conserved germplasm and farmers' varieties

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Introduction

Coconut genetic diversity is essential to ensure sustainable coconut production. This diversity is vital for breeding improved varieties and hybrids which are high-yielding and possessing other traits which are preferred by smallholder producers and adapted to biotic and abiotic stresses. Unfortunately, most of the 38 member countries of the International Coconut Genetic Resources Network (COGENT) do not have, individually, a wide range of coconut genetic diversity. Breeding programmes in some of these countries use a limited range of germplasm, which may not be suitable or adequate to effectively achieve their breeding objectives. Many of them are not fully aware of the characteristics of many coconut accessions worldwide. This constraint has been partly alleviated through the development and dissemination of COGENT's International Coconut Genetic Resources Database (CGRD). At present, there are 1416 coconut accessions conserved in 25 COGENT member countries. This collection is not exhaustive, as more varieties exist in farmers' fields which have recently been identified and characterized under various COGENT-coordinated projects. While some of these are described in the CGRD, the data contained therein do not sufficiently describe the origin, history and morphological and agronomic characteristics of the varieties; other relevant information like conservation sites and global distribution are also non-existent. These data, if incorporated, would be useful not only to coconut breeders but also to other researchers, students and industry players who are working to promote the conservation and use of coconut genetic diversity to benefit smallholders.

Illustrated descriptions of coconut varieties were initially published by a few authors such as Pruhdhomme (1906) and Liyanage (1958). In their papers, a few full pages of drawings or photographs of coconut fruits of different shape and sizes are shown. In some documents related to surveys, characterization or exploration of coconut germplasm, there are also a few pictures and drawings describing various coconut varieties (Whitehead 1966; Le saint *et al*. 1983; Sangare *et al*. 1984; Foale 1987; N'Cho *et al*. 1988). However, such publications are limited in number. The first catalogue of coconut germplasm entitled, 'Coconut descriptors', was published in India in 1995 (Ratnambal *et al*. 1995). In this publication, a variety is described using colour plates of its different parts and two pages of textual information following standardized descriptors (IBPGR 1995). However, this book was mainly designated and written for scientists and researchers, without any ethnobotanical, economical or historical description of the varieties. The second volume of the publication was published in 2001 and distributed in CD-ROM.

To address the situation, COGENT and the Centre de Cooperation Internationale en Recherche Agronomique pour le Développement (CIRAD), initiated the development of two catalogues: the Catalogue of Conserved Coconut Germplasm and the Catalogue of Farmers' Coconut Varieties. The former contains textual and pictorial description of coconut varieties conserved in genebanks of COGENT member countries, while the latter describes coconut varieties that have been identified in farmers' fields under the previous Asian Development Bank (ADB)- and the current International Fund for Agricultural Development (IFAD)-funded 'Poverty reduction in coconut growing communities' projects. The idea of making these fully-illustrated catalogues as printed materials was approved in the 2000 COGENT Steering Committee meeting held in Bangkok, Thailand.

Since then, COGENT and CIRAD have been collaborating to develop and publish these two high-quality catalogues. The objective of this effort is not only to showcase as many referenced varieties as possible, but also to provide comprehensive information (pictures and text) to help stakeholders identify and select the appropriate coconut varieties either for their breeding work or replanting programme. The information in the catalogues is presented to make them attractive and understandable to the general public while retaining their technical soundness to be appreciated by scientists and researchers, thereby appealing to a much wider spectrum of audiences.

In this catalogue, each variety is described using one-page picture plate and one-page text, as detailed below:

Textual information

In the textual description (Annex 1), each variety is described following the headings below:

- **The international name and abbreviation** of the variety;

- **The author(s)** of the text;
- **History and description:** Historical, botanical and morphological data of the variety;
- **Identification:** Description of the traits that differentiate the variety described from other varieties. This part also has information on the relationship of the variety to other varieties with which it is commonly confused;
- **Yield and production:** Contains data on production of fruits, copra or toddy, depending on the uses;
- **Other topics:** Any other interesting facts about the variety, including common pests and diseases and breeding techniques; and
- **References** for additional information regarding the variety.

The picture plate

In the picture plate (Annex 2), the international name and abbreviation of the variety are located on the top right hand side of the sheet. Each plate is a composite of the following six pictures for each entry:

1. ***Whole palm.*** This picture of coconut palm in the field shows the entire tree from the bole to the tip of its leaves. Dry leaves and weeds in excess are removed before making the picture. If needed, two to three leaves are also generally cut in order to have a better view of bunches and fruits in the crown. Some of the pictures could also show workers, farmers or researchers for ethnology, and also as basis of comparison of the tree's height.
2. ***Fruits (whole and split).*** This is a composite picture showing 12 fruits: three young fruits (9-10 month old), three fully-matured fruits (12 month old) with brown-grey epidermis, three nuts split longitudinally (vertically) and three nuts split equatorially (horizontally). Each is arranged according to size (i.e., big, medium and small) to give an idea of the existing phenotypical variation. The three immature fruits are also chosen for their different colours, if available, especially for the Talls. A measuring unit (20 cm) is also included for size comparison;
3. ***Fruit bunches.*** This shows fruit bunches or a single bunch on the tree before all the fruits turns completely brown-grey. Most fruit bunch photos show one mature bunch and a younger bunch, as the latter may have traits that are also useful for varietal identification;
4. ***Inflorescence.*** This shows a fully-opened inflorescence on the palm, with one third to half of the male flowers already fallen and with a representative number of female flowers. It will not be possible to count the male nor the female flowers from the pictures but

the shape, colour and size of the inflorescence vary with the number of female flowers and the stage of maturity;

5. ***Husked nuts*.** This picture is located at the top left of the page next to the name of the variety, arranged as small, medium and big. These pictures were included mainly because people, especially from the Northern Hemisphere, often know coconut only as husked nuts. In addition, there is a strong genetic variation in the size, the shape and the position of the three coconut 'eyes' that is not yet included in the IPGRI standard descriptors for coconut;
6. ***'Special' picture*.** Oval-shaped, at the top right side of the plate, this photo can show any additional, interesting or unique feature of the variety (e.g. pink colour inside the husk, detail of inflorescence, special aspect of the young palm, ethnobotanical aspect, etc) or could also show the whole crown of the palm.

This catalogue may not contain all of the varieties conserved in COGENT's member countries and countries participating in COGENT's poverty reduction project, but this certainly covers a vast majority of these varieties. This catalogue is envisioned to serve the needs of researchers, students, policy officers of national programmes and other players of the coconut industry in general and help promote the coconut as a prime economic commodity.

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Annex 1. Sample textual description (varietal writeup) (Malayan Red Dwarf)

Malayan Red Dwarf (MRD)

R Bourdeix, A Othman and JL Konan

History and description

The Dwarf palms of Malaysia – in red, green and yellow forms- were supposedly introduced from Indonesia between 1890 to 1900. The colour of the seedling sprouts, the leaf stalks, the inflorescence and the immature fruit is not really red but more like bright orange.

The palm generally has a thin stem, about 22 to 25 cm in diameter, with no bole. When growing conditions are good, it may have a small bole (35 to 40 cm in diameter).

The youngest leaves at the top of the palm are quite soft. Its upper canopy resembles dishevelled hair, compared, for example, with the Cameroon Red Dwarf (CRD), which has a straight and erect canopy.

Because of its short peduncle, the bunch is well supported by the leaf petioles. The reproduction system has been described as direct autogamy. MRD characterization data can be found in at least seven countries: Brazil, Côte d'Ivoire, Fiji, India, Philippines, Tanzania, and Vanuatu.

Identification

More than 30 types of Red Dwarfs are referenced worldwide. Some of them look very similar to the Malayan type: Red Dwarfs from Sri Lanka, from Chowgat in India, from Nias in Indonesia, from Chumpon in Thailand, and even from Cuba. Molecular analysis techniques will help to determine if these Red Dwarfs are identical or not.

Other Red Dwarfs can be easily distinguished from the Malayan type. CRD bears pear-shaped fruits with paler orange colour. Some Red Dwarfs from the Pacific region produce bunches with long peduncle and numerous smaller fruits having a more intense red-orange colour (such as the Tahiti Red Dwarf). Fruits of some other Red Dwarfs from Papua New Guinea have a tit or lug at the bottom.

Yield and production

MRD produces medium-sized, oblong fruits that are generally bigger than those of the Malayan Yellow Dwarf. The average fruit weight ranges from 668 g (in Brazil) to 1080 g (in Vanuatu). Inside the fruits, the nuts are almost spherical and weigh from 443 g to 755 g on average.

Under ideal agronomic conditions, MRD starts flowering on the second to the third year and may produce about 70-90 fruits per palm per year (without irrigation).

MRD is mainly an ornamental palm, planted in homegardens. Water from young nuts is sweet and tasty, but not as sweet as some green Dwarfs. The albumen is thin and gives rubbery copra. MRD is sensitive to drought and is subject to alternate bearing.

Other topics

The MRD is tolerant to the Lethal Yellowing Disease (LYD) of Jamaica (Romney 1980) but sensitive to the LYD found in Tanzania and Ghana.

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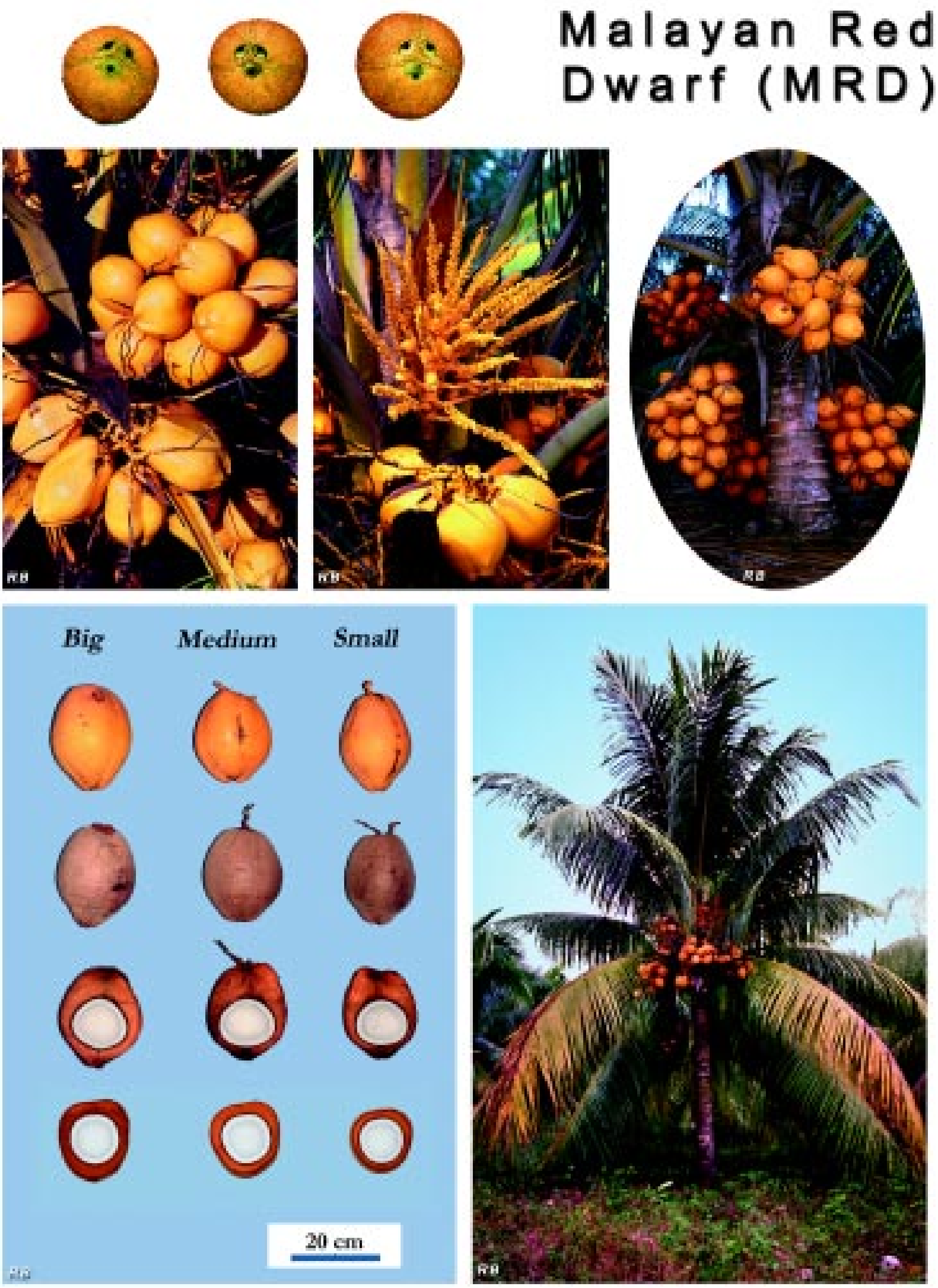
Annex 2. Sample picture plate (Malayan Red Dwarf)



Public awareness initiatives in coconut
Catalogue of high-value coconut products

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To complement *ex situ* conservation of coconut diversity, COGENT has been trying to convince coconut farmers to conserve their 'good' local coconut varieties *in situ* and on farm. This would have the advantage of conserving already adapted germplasm and would promote natural selection through use. However, farmers say that unless they earned more from coconut, they would not be able to conserve their germplasm.

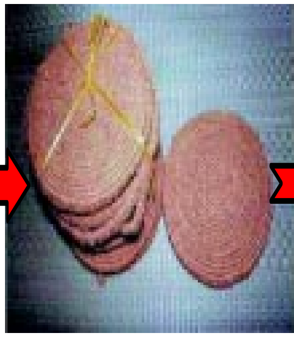
Recognizing this problem, COGENT developed and implemented a strategy of increasing farmers' incomes through the production and marketing of high-value products from all parts of the coconut. Once farmers could earn more, they were then ecnouraged to maintain and propagate their local varieties. The strategy proved to be successful. The COGENT-coordinated, Asian Development Bank (ADB)-funded 'Poverty reduction in coconut growing communities' project (2002-2004) increased farmers' income by up to 3-5 times. In this project, farmers also planted over 50 000 seedlings of selected local varieties.

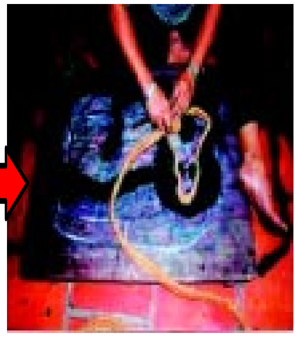
Using the same strategy, the International Plant Genetic Resources Institute (IPGRI), through COGENT, is promoting the production and marketing of high-value products from coconut meat, husk, shell, wood, water and leaves to increase income of coconut farmers. To support this, a 'Catalogue of high-value-coconut products' is being developed by COGENT. The idea of product diversification derived from all parts of the coconut will promote new value-added products and utilize the full potential of the crop. The village-level technology provides opportunities for resourceful communities with sufficient labour force to be productive, creative and innovative in producing various high-value products. The catalogue, which will be published in 2006, will contain illustrated, step-by-step procedure and a textual description (with profitability data) to produce various high-value products from the different parts of the coconut. The simple procedures can be easily followed by farmers, women and even the youth, using simple tools and equipment and do not require heavy capital outlay.

Annex 1 presents a sample illustrated procedure for producing coconut fibre-based animal-shaped doormat; Annex 2 shows the textual description and other information for producing this high-value product as it would appear in the catalogue.

Annex 1. Sample illustrated procedure (making animal-shaped coconut fibre-based doormats in Sri Lanka and Vietnam) [1]

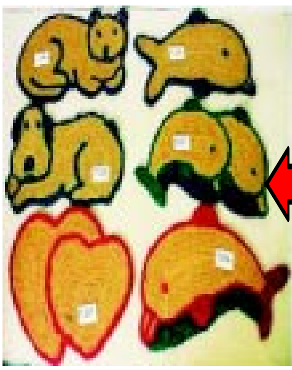

Prepare double-ply fibre-based ropes


About four to five meters of double-ply rope are needed to produce a single dorrmat


Weave the double-ply ropes following the drawn pattern, using the nails on the wooden board as guides


Weave in the dye-coloured double-ply ropes according to the design drawn on the board


Sew the mat horizontally and vertically to hold it together


Some samples of the finished product

[1] *By Vo Van Long, Coconut Scientist, Oil Plant Institute of Vietnam (OPI), Ho Chi Minh City, Vietnam; pictures courtesy of Ajith Samarajeewa, Research Officer, Coconut Research Institute (CRI), Lunuwila, Sri Lanka*

Annex 2. Sample writeup for making animal-shaped coconut fibre-based doormats

Procedure for making animal-shaped doormat

Vo Van Long
Oil Plant Institute (OPI), Ho Chi Minh City, Vietnam

Animal-shaped doormat is just one of the many attractive products that can be made from the coconut fibre. It is used either for wall decoration or as a mat placed at the entrance of a house to wipe dirt from the shoes or slippers. In Vietnam and Sri Lanka, these animal-shaped doormats are very popular among local and foreign tourists and are mostly made for export.

Preparing the 'twin-ropes'
Single-ply coconut ropes mixed with some jute ropes are used to make twin ropes. The coconut rope is weaved around the jute rope to produce twin ropes of about 4-5 meters long each. Depending on the design preferences of the customers, twin-ropes can be dyed with different colours.

Weaving the doormat
The materials required include a wooden frame, nails, hammer, scissors, big needle and chalk.

a. Draw the desired animal shape on the wooden frame using chalk.
b. Weave the twin ropes into the frame following the drawn animal shape. Use nail and hammer as necessary to make the weave secure and compact. Continue weaving the twin-ropes towards the inside of the pattern. For design, use colored twin-ropes at the border first and working your way into the pattern, securing the fibre rope into the shape with nail and hammer. Remove nails as you weave from layer to layer into the shape.
c. Use coloured twin-ropes in the relevant portions of the doormat based on the design.
d. When the doormat is completed, sew it horizontally and vertically using a big needle and jute rope, making sure that the doormat will not fall apart when taken out of the frame. Clean by cutting the extra fibres protruding from the doormat.

Packaging
Finished products are usually packed in cartons or boxes for delivery to customers.

One doormat maker can produce an average of 10 animal-shaped doormats per day. The estimated average production cost per doormat is US$0.57 (US$0.45 for materials and US$0.12 for labour). At a selling price of US$0.78, one can earn a gross profit of US$0.21 per piece or US$2.10 per day. Animal-shaped doormats could be sold in handicraft and souvenir shops, flea markets, department stores and general merchandise shops.

Public awareness initiatives in coconut
Catalogue of coconut food recipes

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Introduction

COGENT firmly believes that one of the best ways to promote the conservation of coconut is by promoting its domestic consumption, particularly its use in food and related food products. It is a fact that in many countries, coconut is widely used as an ingredient in food. Indeed, for certain countries, a meal would not be complete without the spicy curry or sweet dessert that has coconut milk as its main ingredient.

Nutritional value of coconut

Besides being widely used in cooking and in preparing food worldwide, coconut is also used traditionally for medicinal purposes to increase and improve the body's internal and external health, which is widely practiced in most coconut producing countries.

Coconut oil

Coconut oil has been a lifesaver for many people. The health and nutritional benefits derived from coconut oil are unique and compelling. Medium chain triglyceride, a fraction of coconut oil has been identified as an important, medically efficacious food. Indeed, diets for critically ill children, premature infants and hospitalized patients contain medium chain triglycerides as principle source of fat. Coconut oil, when used in usual diets containing all classes of fat, proves to be hypocholesterolaemic. Chemically, coconut oil is rich in fatty acids of 12 carbons or less, classified as Medium Chain Fatty Acids (MCFA).

Coconut water

Coconut water is a health drink with proven therapeutic benefits for those who are prone to high blood pressure. Because of its high glucose and fructose content, coconut water serves as a good source of intravenous fluid, and could also be used for oral rehydration.

Traditionally, some people drink coconut water not only to prevent the formation of but also to facilitate the removal of kidney stones. In some rural areas, drinking coconut water is also practiced to cure measles.

Coconut milk

Coconut milk has soothing and cooling effects on the body. It also stimulates growth of hair. Some people use either raw or cooked coconut milk as routine hair treatment or maintenance. Hair will become stronger; thicker, shinier and generally healthier.

Coconut flour

Coconut flour has great value as an ingredient in health food. When mixed with wheat flour, it supplies the amino acids which are lacking in the latter. Coconut flour also has a high-fibre content which helps facilitate the removal of harmful toxins from the body by promoting regular bowel movement (Rethinam 2003)

The catalogue of coconut food recipes

In view of the above, COGENT decided to compile coconut food recipes from its member countries in Southeast Asia, South Asia, South Pacific, Africa and the Indian Ocean, and Latin America and the Caribbean (see related article on COGENT's history and achievements for a complete list of the network's member countries, this chapter). Under this activity, COGENT will produce and disseminate worldwide a publication entitled, 'Catalogue of Coconut Food Recipes', which will contain the various coconut food recipes as documented from its member countries. The recipes featured in the collection will include those that are commonly found in the households of coconut farmers in the rural areas of these countries and which are easy to prepare and the ingredients are readily available.

The catalogue aims to (1) promote the nutritional value of coconut and coconut-based food products; (2) encourage the domestic use and consumption of coconut, and, therefore, promote its conservation; and (3) help generate employment and promote entrepreneurship especially among farmers, women and the youth in food-related business, thereby contributing to increasing household incomes.

COGENT will also feature the coconut recipes in the COGENT Newsletter as part of its overall public awareness strategy to promote the many uses of coconut, and in the COGENT webpage for a wider access worldwide. The recipes will be also be provided to the local media (i.e. newspapers and magazines) of the member countries, to nutrition/ home economics teachers and extensionists, and to associations of hotels and restaurants worldwide.

The catalogue will have four general categories: (1) soups; (2) main dishes; (3) snacks; and (4) desserts (see Annexes 1 to 4 for sample entries), and further subdivided by country from where the recipe came from. Each recipe entry will contain the following:

1. The country where the recipe was documented;
2. The local name of the dish and its English translation, if any;
3. The author or documenter of the recipe;
4. The specific place in the country where the dish is popular;
5. A picture of the dish;
6. The ingredients needed; and
7. The instructions for cooking or preparing the dish.

This compilation of indigenous coconut-based food recipes will be published and distirbuted to target recipients in 2006.

References

Rethinam, P. 2003. Health and nutritional aspects of coconut. 155-167 *In:* KI Vasu and PK Thampan (eds). Coconut for rural prosperity. APCC, Jakarta, Indonesia. 299p.

KI Vasu and PK Thampan (eds). 2003. Coconut for rural prosperity. APCC, Jakarta, Indonesia. 299p.

Annex 1. Sample 'Soup' entry

Country: Malaysia
Local Name: Sup Ayam Herba
English Name: Herbal Chicken Soup in Coconut Pot

Author: Wong Thiam Lim
Place where dish is popular: All states of Malaysia

Type of dish: Soup ***Serves 1-2 persons***

Ingredients:
1 big coconut
400 g chicken
5 g yuk chuk (Chinese herbs)
5 g Sa Sam (Chinese herbs),
5 g boxthorn fruit or qi zi (Chinese herbs)
1/4 tsp salt
500 ml boiled water

Cooking Instructions:
1. Dehusk the coconut; cut the top cleanly to open and drain away all the coconut water.
2. Put all ingredients into the coconut with its meat intact.
3. Cover the top and tie with string.
4. Steam over low fire for 2 hours.
5. Serve while hot.

Annex 2. Sample 'Main Dish' recipe

Country: Thailand
Local Name: Phaneang Mu
English Name: Pork Curry with Vegetables

Author: Peyanoot Naka
Place where dish is popular: Bangkok

Type of dish: Main Dish ***Serves 4-5 persons***

Ingredients:

1 cup sliced pork
¾ cup coconut milk
1 ½ tablespoons fish sauce
3 pcs Kaffir lime leaves, finely cut
5-6 basil leaves
1 ½ tablespoons red curry paste*
1 cup coconut cream
1 tablespoon sugar
1 green chili pepper, cut into thin strips
1 cup coconut palm heart, sliced

Red Curry paste ingredients:

10 large dried hot peppers
4 tablespoons garlic, chopped
2 ½ tablespoons lemon grass, sliced
2 ½ teaspoons coriander seeds
1 teaspoon cumin (Yira)
1 teaspoon kaffir lime skin, chopped
1 ½ teaspoons shrimp paste
3 tablespoons shallot, chopped
3 tablespoons siamese ginger, chopped
1 tablespoon salt
1 teaspoon pepper

Cooking Instructions:

1. Pound all the Red Curry paste ingredients together until the resulting mixture is smooth.
2. Using a wok or pot, cook the coconut cream over low heat until oil appears. Add red curry paste and stir for 2 minutes.
3. Add the sliced pork. Stir 2-3 times. Add fish sauce, sugar and coconut milk. Bring to a boil. Cook for 5-10 minutes.
4. Put in green chili pepper. Remove from heat. Top with kaffir lime leaves and basil leaves when serving. Serve with cooked rice or bread.

Annex 3. Sample 'Snack' entry

Country : Tanzania
Local Name : Kashata
English Name : -

Authors: Joyce Paul, V Chokala and V Kiwia
Place(s) where dish is popular: All regions along the coastal belt

Type of dish: Snack ***Serves 7-9 persons***

Ingredients:
1kg white sugar
½ kg grated coconut
2 cups water

Cooking Instructions:
1. Mix sugar with water.
2. Boil sugar-water mixture until sugar melts.
3. Add the grated coconut to the sugar solution. Stir for 30–40 minutes until solution thickens.
4. Spread the mixture evenly on an aluminium tray lined with oil.
5. While still hot, cut the mixture into bite-size pieces of desired shapes.

Annex 4. Sample 'Dessert' entry

Country: Vietnam
Local name: Banh Dau Do
English name: Red Bean and Coconut Pudding

Author: Oil Plant Institute of Vietnam
Place where dish is popular: Ho CHi Minh City

Ingredients:
150g of red beans
3/4 cup of concentrated milk
300g of coconut water
140g of corn flour
1 1/3 of cups sugar
30 strips of white agar

Cooking Instructions:
1. Mix corn flour, fresh coconut water and concentrated milk together.
2. Soak agar for half hour. Drain.
3. Wash and boil red beans in 6 cups of water.
4. Simmer over low heat for 1½ hours until beans are soft.
5. Remove cooked beans from boiling water. Set aside boiled water.
6. Boil agar in 5 cups of of the red beans water until agar is dissolved.
7. Add sugar, then gradually pour in corn flour mixture. Keep stirring until the mixture thickens.
8. Put in the red beans and bring to boil. Pour the boiled mixture in a basin.
9. Put in refrigerator.
10. Serve chilled.

CGIAR's support to coconut research

GJ Persley
Doyle Foundation and Chair, Coconut Support Group, Consultative Group on International Agricultural Research (CGIAR)

Introduction

The purpose of this paper is to summarize the past and present international efforts in coconut research and discuss future perspectives on international coconut research that would serve the needs of the commodity and those who depend on it.

Historical perspective

The first recorded coconut research was conducted 250 years ago in Indonesia, where a description of coconut cultivars was recorded in literature. A brief chronology of coconut research over the last century is given in Table 1.

The possibility of an international initiative in coconut research was first discussed with the Asian and Pacific Coconut Community (APCC) at its meeting in Bangkok in May 1989 and in a subsequent APCC-sponsored workshop in Singapore in September 1989. The attention of the international agricultural research community had been drawn to coconut because of its importance as a multi-purpose tree, both a local and an export commodity, grown largely by smallholders - often in fragile environments where there were few prospects for other crops.

Coconut has been characterized by a 'stop/start' approach to research that was under-funded at national, regional and international levels. The need for international cooperation in coconut research to bring together a critical mass of expertise and resources to solve some of the problems facing the industry has long been recognized amongst coconut producing countries, researchers and development agencies. Several proposals were put forward in various international fora between 1960-1980, all of which lapsed.

The Consultative Group on International Agricultural Research (CGIAR) recognized the importance of coconut as the smallholder crop most in need of international attention, in its review of priorities and strategies in 1996. The long-term nature of coconut research, the history of discontinuity and lack of adequate support in funding, the prospects of a high return on research investments and the likely distribution of benefits to smallholders and consumers in developing countries made coconut a suitable target for international support.

The CGIAR requested its Technical Advisory Committee (TAC) in 1987 to undertake a consultative process to identify: 1) priority problems that affect coconut production, 2) those problems that could be addressed through research; and 3) new approaches to address those researchable issues that are international in character, and beyond the scope of any one country to resolve.

This process was undertaken in 1988-89 with the assistance of the Australian Centre for International Agricultural Research (ACIAR) and other CGIAR members, APCC and the coconut research community. The feasibility study on an international initiative in coconut research identified: 1) the current status and future trends for coconut within the world fats and oils market; 2) the importance of coconut as a smallholder crop in coastal and island communities; 3) productivity constraints; 4) current national, regional and international research efforts; 5) priority problems requiring an international approach; 6) goals of an international initiative; and 7) possible institutional options.

The findings of the feasibility study is given in detail in a publication entitled 'Replanting the Tree of Life: Towards an International Agenda for Coconut Palm Research' (Persley 1992). The key elements are summarized below.

Constraints analysis

The constraints to coconut production were identified as: 1) Low productivity of many trees due to age, and poor nutrition; 2) the lack of success in many replanting programmes; 3) fluctuating productivity, due to climatic and other events; 4) losses due to pests and diseases including several lethal diseases of unknown etiology; and 5) inefficient handling and processing with limited added-value products for national and export markets.

Rationale for R&D

The rationale for further R&D is based on: 1) the importance of coconut as a smallholder crop produced largely for domestic consumption, with about 50 million people involved in its cultivation and a further 30 million people in Asia directly involved in its processing and marketing; 2) the growing demand for vegetable oils as populations increase; 3) the predictions of decreasing production available for export; 4) the price premiums paid for lauric acid oils for industrial uses; and 5) declining competitiveness of coconut in relation to crops such as oilpalm and rapeseed, where there have been major productivity gains, in the order of 10% per year for oilplam and 7% for rapeseed.

Some of the constraints can be addressed through research to increase the productivity of the crop and the coconut-growing lands and add value to the commodity after harvest.

Research and development needs and opportunities

The major research and development needs are: 1) conservation of the genetic resources, and selection and propagation of higher yielding local varieties and hybrids that are locally adapted, and pest and disease tolerant; 2) control of the major pests and diseases, especially the lethal diseases that are killing millions of trees each year; 3) increasing the productivity and sustainability of existing plantings by improved farming systems; 4) development of more efficient means of handling and processing; and 5) diversification of the products derived from coconut and active promotion of new added-value products in the marketplace.

Implementation options

The advantages and disadvantages of various options for providing additional international support were considered. The options included: 1) additional support for national programmes; 2) an international coconut research center; 3) international/regional coconut research networks; 4) an international coconut research council; and 5) a coconut R&D consortium. These options included ones that could be incorporated within the CGIAR system and others that could be conducted under international auspices outside the CGIAR system.

TAC recommendations

TAC recommended to the CGIAR in 1990 that coconut be included in the CGIAR portfolio of activities. TAC farther recommended that the research areas that warranted international efforts were within the fields of: 1) germplasm collecting, conservation, evaluation and enhancement; 2) the control of pests and diseases; 3) the productivity and sustainability of coconut-based systems; 4) efficiency and added value in post harvest handling and utilization; and 5) socioeconomic issues, especially the factors that influence farmers' participation in rehabilitation and replanting coconut land.

With regard to implementation arrangements, TAC recognized a clear need for networks with a strong enabling component to fund research. TAC also recommended that an international germplasm research unit be established in Asia, in association with an international network on genetic resources, possibly managed by the International Plant Genetic Resources Institute (IPGRI). The programme of an international network for coconut genetic resources was developed at an international workshop held in Cipanas, Indonesia in 1991 (IBPGR 1992).

With regards to the important problems needing to be addressed beyond germplasm-related issues (i.e., pests and disease control, production systems, post-harvest technology and socioeconomics), TAC noted the recent establishment of the Bureau for the Development of Research in Tropical Perennial Oil Crops (BUROTROP), with its interests in supporting and coordinating oilpalm and coconut research, and its special interests in coconut improvement. It also recognized the ongoing work of APCC as an intergovernmental agency in support of the coconut industry, with particular interests in processing and value-added products and socioeconomic issues as well as production issues.

TAC reiterated its earlier recommendations to the CGIAR for the inclusion of coconut within the CGIAR portfolio by the inclusion of the recommendations on coconut within the CGIAR report on Priorities and Strategies (CGIAR 1990, 1992).

CGIAR decisions on international coconut research

In the light of the above recommendations from TAC, the CGIAR at its meeting in Istanbul in 1992 formally agreed to the inclusion of coconut within its portfolio as a CGIAR commodity. It further agreed with TAC's analysis and recommendations as to the above five priority areas warranting additional international support. It decided that initial priority should be given to genetic resources collecting, conservation, characterization and utilization. Germplasm was considered to be the research area most international in scope, most at risk and with widest likely payoff for many countries. The CGIAR encouraged IPGRI to expand its activities on coconut research and to host the newly-established International Coconut Genetic Resources Network (COGENT).

Critical elements in international initiatives

The wide consultative process sponsored by the CGIAR analyzed the needs and opportunities and identified R&D priorities and implementation options for international coconut research. The critical elements identified for international initiatives were: 1) Identify a set of priority problems of global significance; 2) provide international auspices for a programme of genetic resources collecting, conservation, exchange and utilization; 3) provide an enabling financing mechanism for research on the priority problems able to be undertaken by scientists worldwide on a contractual basis; and 4) provide a mechanism for continuity of funding in coconut research.

Present status of international coconut research efforts

The International Coconut Genetic Resources Network (COGENT)

COGENT was established in 1992 with the goal of improving the productivity and profitability of coconut through the better conservation, collecting, characterization and utilization of germplasm. It has 38 member countries. COGENT is governed by a Steering Committee of representatives of member countries and operates through regional and sub-regional networks, and specific task forces. IPGRI provides a secretariat through its Asia, Pacific and Oceania regional office in Malaysia. COGENT's budget in 2000 was US$ 2.6 million, comprised of approximately US$ 1.4M from international sources and US$1.2M from contributions of member countries to agreed international activities.

Since its inception, COGENT has evolved into a global network, both in terms of its geographic coverage and its evolving agenda. The agreed research agenda covers genetic resources collecting, conservation, characterization and utilization.

International research collaboration has been established on embryo culture, disease indexing, genome mapping, molecular markers, breeding methodologies, farmer-participatory germplasm selection for local needs, value-added coconut products and socioeconomics, including farmer responses to hybrid utilization.

The aim of the utilization studies and pilot projects in 14 countries are to find new ways to increase farmer incomes from coconut cultivation. The progress and achievements of COGENT are summarized in a related article in this chapter.

A major achievement is the COGENT/APCC initiative to establish a multi-site international coconut genebank (ICG) to conserve coconut genetic resources in perpetuity and facilitate their utilization. The first ICG Host Country Agreement was signed by the Government of India, FAO and lPGRI/COGENT in May 1999. The Governments of Indonesia, Papua New Guinea and Cote d'Ivoire have now signed similar agreements. The field genebanks, associated research facilities and germplasm exchanges are now being developed.

Future perspectives

The global context

The world today is a rapidly changing environment. Important trends that affect R&D include:

- The tensions between globalization and the aspirations of local communities;

- International treaty obligations, for example on trade, biodiversity and climate change;
- The changing roles of the public and private sector;
- The new developments in modem science, including biotechnology;
- The public debate as to the risks and opportunities in the use of genetically modified organisms; and
- Environmental trends, with pressure on land, water and natural resources.

New CGIAR vision and strategy

In the 1980s, the CGIAR was developing its new vision and strategy for international agricultural research in the 21st century. Key elements of-this strategy are to focus on:

- Regionally-determined priorities that contribute to poverty alleviation;
- Greater emphasis to South Asia and sub-Saharan Africa;
- Use of all aspects of modem science, including modem molecular biology and geographic information systems;
- Defining the 'CGIAR heartland', where international R&D efforts have comparative advantage;
- Measuring impact of strategic research efforts; and
- Experiment with new means for implementation of R&D, with a broader range of partners and greater flexibility.

Future prospects for coconut

The challenge is how to position coconut in the changing world scene and the new vision and strategy that is developing for international agricultural research. Coconut is well-positioned in that it is a multipurpose crop of poor people and fragile environments.

New elements such as farmer participatory approaches are being used in priority setting in some R&D programmes. Modem science is being applied through the use of modem biotechnology. In terms of research modalities, there is successful international cooperation involving APCC, COGENT and BUROTROP.

In terms of new modalities for international agricultural research, the strengths of COGENT are its committed participants, with 38 countries participating in the various activities, nationally, regionally and internationally and through a number of specific Task Forces. It also has an active Steering Committee responsible for its programme and strategy, There is potential to build on the success of COGENT in examining the long term prospects for coconut research, teaming the lessons from past experience while focusing on future needs and opportunities.

Future R&D needs and opportunities

The need is to ensure that future international R&D efforts meet the needs of the coconut industry and add value to national efforts. New investments are needed in both coconut research and development to resolve some of the long term issues facing the industry. These investments need to stem from the commitment of both public and private sector commitments to coconut in producing countries. Potential investors in R&D are the public and private sectors in coconut producing countries, coconut export industry, both exporters and importers, bilateral and multilateral donors and the multilateral development banks.

In terms of new international efforts there is a need to answer and establish the following:

- What are the priorities for international research efforts over the next decade?
- What is the R&D strategy?
- What will be the measurable indicators of success?
- What is the financing plan?
- Who will do the R&D?
- What partnerships and strategic alliances are necessary?

Conclusion

The lessons learned from past experience in international coconut efforts are that the critical elements for the success of future international initiatives are: 1) Identification of a set of priority problems of global significance; 2) provision of an enabling financing mechanism by which research on the priority problems may be undertaken by scientists worldwide; 3) provision of international auspices for a program of genetic resources collecting, conservation, exchange and utilization; and 4) provision of a means for continuity of funding in coconut research.

Much progress has been made in international coconut R&D efforts over the past decade. This has been the result of careful planning and meaningful consultations. There is a need now to plan with similar care for the next decade, determine a focused set of priorities and expected outcomes, strengthen the partnerships and strategic alliances necessary to achieve these outcomes, and mobilize the necessary finance, from national and international resources.

Future national and international R&D efforts will then have a high chance of success in alleviating the constraints affecting the coconut industry today, contribute to increasing the long term profitability and sustainability, and increase the competitiveness of coconut, for the benefit of all who depend on the 'Tree of Life'.

Table 1. Chronology of international coconut research (1900-2000)

1900-to date	National programmes in several countries of varying size and strength.
1940 onwards	French-led international coconut breeding and improvement programmes.
1960-1980s	Many national/regional/bilateral research and development projects, including replanting schemes
1986	Feasibility study of international coconut initiative agreed by TAC and CGIAR.
1987-1990	CGIAR-sponsored consultations on coconut industry constraints and R&D needs, leading to three papers prepared for TAC on international R&D priorities and implementation options.
1989	APCC meeting, Bangkok endorsed CGIAR coconut initiative.
1989	APCC/ACIAR/IDRC sponsored Singapore workshop elaborated on coconut R&D priorities and implementation options for international initiative, as basis for TAC recommendations
1990	TAC recommendations to CGIAR on priority areas for international support, within germplasm, pests and diseases, production systems, post harvest technology and socioeconomics. European initiative (BUROTROP) established to coordinate research on oil palm and coconut. Established Board of Administrators. Conducts coordination, programme and information activities, including workshops in different regions.
1991	International workshop, Cipanas, Indonesia to elaborate international program on genetic resources conservation, utilization and related areas, including diseases affecting international germplasm exchange.
1992	TAC reiterated recommendations to CGIAR for inclusion of coconut in new CGIAR priorities and strategy. CGIAR formally accepts coconut as a CGIAR commodity, with first priority for international support and action on genetic resources collecting, conservation, characterization and utilization.
1992	COGENT (International Coconut Genetic Resources Network) established, with Steering Committee of representatives from coconut producing countries. IPGRI to provide secretariat.
1992-1999	Thirty-five countries progressively became members of COGENT Regional/sub-regional networks established in Asia/Pacific, Africa and LAC.
1992 to date	Annual meetings of COGENT Steering Committee, and meetings of COGENT regional and sub-regional networks and task forces, held in conjunction with BUROTROP and APCC. Specific Task Forces on International Coconut Genebanks, safe exchange of germplasm, farming systems and other topics established under auspices of COGENT Several specific research projects initiated, including: (1)

	COGENT/IPGRI/ ADB inter-country project on genetic resources (14 countries); and (2) COGENT/IPGRI/IFAD international project on genetic resources utilization (20 countries). International research collaboration established on disease indexing, genome mapping, molecular markers, breeding methodologies, farmer participatory germplasm selection for local needs, value-added coconut products and socioeconomics, including farmer responses to hybrid utilization
1998	First agreements on establishing an International Coconut Genebank (ICG) signed (at CGIAR meeting Beijing May 1999), by Government of India, FAO and IPGRI/COGENT, with India as host country as part of COGENT's initiative on multi-site ICG to conserve coconut genetic resources in perpetuity and facilitate their utilization
1998	Second agreement on the ICG signed by Government of Papua New Guinea, FAO and IPGRI/COGENT.
1999	Two other ICG agreements signed by FAO, IPGRI and Governments of Cote d'lvoire and Indonesia. Final agreement is under negotiation with Government of Brazil.
2000	Annual meeting of COGENT Steering Committee and ICG workshop held in conjunction with APCC's International Coconut Conference, Chennai, India (July 2000). COGENT Annual workplan and budget approved by Steering Committee. COGENT budget in 2000 is approximately US$ 1.2 million from COGENT member countries commitments to agreed international activities, including the genebanks and US 1.4 million from external sources (CGIAR donors and other development agencies), making a total annual investment of about US$ 2.6 million. The estimated COGENT budget for 2001 is approximately US$3 million.
After 2000	See related article on COGENT in this chapter

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The International Coconut Genetic Resources Network (COGENT): Its history and achievements

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Introduction

The possibility of an international initiative in coconut research was first discussed with the Asian and Pacific Coconut Community (APCC) at its meeting in Bangkok in May 1989 and at a subsequent meeting in Singapore later that year. At about the same time, the Technical Advisory Committee (TAC) was tasked by the Consultative Group on International Agricultural Research (CGIAR) to undertake a consultative process to identify: 1) priority problems that affect coconut production; 2) those problems that could be addressed through research; 3) new approaches to address those researchable issues that are international in character and beyond the scope of any one country to resolve. The priorities identified for international effort were: 1) germplasm collecting, conservation, evaluation and enhancement; 2) pests and diseases control, especially the lethal diseases; 3) improving productivity and sustainability of coconut-based systems; 4) increasing efficiency and added value in post harvest handling and utilization; and 5) addressing socioeconomic issues, such as the factors that influence farmers' choices in replanting coconut land.

On 8-11 October 1991, the International Board for Plant Genetic Resources or IBPGR (renamed International Plant Genetic Resources Institute or IPGRI in 1992) organized an international workshop on coconut genetic resources in Cipanas, Indonesia involving leading coconut researchers from 15 countries. The workshop participants recommended that an international coconut genetic resources network be established with IBPGR serving as the executing agency for Phase I (first five years) of this network and nominated the initial members of the Steering Committee. Based on the results of the TAC consultation process, the CGIAR decided to include coconut in its research portfolio in 1992 after studies indicated that international support and global coordination of research in coconut is essential to make it more productive and beneficial to smallholder coconut farmers. The CGIAR and TAC recognized that international support to coconut research was needed as many coconut-producing countries lacked both the human and material resources to conduct expensive and time-consuming research. Thus, it tasked IPGRI (then IBPGR) to undertake research on coconut genetic resources which was one of the five identified priority research areas that deserved international support. Accordingly, IPGRI included coconut genetic resources in its plant genetic resources research programme and organized the International Coconut Genetic Resources Network (COGENT) to implement this mandate. Dr Gabrielle Persley, then working with the Australian Centre for International Agricultural Research (ACIAR), and later with the Doyle Foundation, is credited with making a major contribution to COGENT for supporting case studies and organizing efforts to convince the CGIAR that coconut research need international support; in commissioning external reviews to evaluate the progress of COGENT and in developing its strategic plan; and in organizing the CGIAR Coconut Support Group to generate support for COGENT priority activities. To organize COGENT, IPGRI engaged Dr Hugh Harries as a Consultant in 1991 who helped develop the first five-year work plan and who eventually suggested the acronym 'COGENT' for the network. Mr Gerardo Santos served as the Acting Coordinator of COGENT for a few months in early 1993. Dr Michel de Nuce followed briefly as Coordinator for the rest of 1993. From thereon, Dr Pons Batugal served as Coordinator for the last 11 years, i.e. from 1994 to date. Starting with the 15 countries that participated in the Cipanas, Indonesia workshop, COGENT has rapidly developed into an active global Network currently involving 38 coconut producing countries (Table 1; see also Annex 1 for list of partner institutions in COGENT member countries).

Table 1. COGENT member countries

Southeast and East Asia	South Asia	South Pacific	Africa/Indian Ocean	Latin America/ Caribbean
1. China	1. Bangladesh	1. Cooke Is.	1. Benin	1. Brazil
2. Indonesia	2. India	2. Fiji	2. Cote d'Ivoire	2. Colombia
3. Malaysia	3. Pakistan	3. Kiribati	3. Ghana	3. Costa Rica
4. Myanmar	4. Sri Lanka	4. Papua New Guinea	4. Kenya	4. Cuba
5. Philippines		5. Solomon Is.	5. Madagascar	5. Guyana
6. Thailand		6. Tonga	6. Mozambique	6. Haiti
7. Vietnam		7. Vanuatu	7. Nigeria	7. Honduras
		8. Samoa	8. Seychelles	8. Jamaica
			9. Tanzania	9. Mexico
				10. Trinidad-Tobago

Goal, objectives and organizational structure

COGENT's goal is to improve coconut production on a sustainable basis and increase incomes in developing countries, through improved cultivation of the coconut and efficient utilization of its products and by-products. The objectives of COGENT are to: 1) establish and maintain an international coconut database on existing and future germplasm collections; 2) encourage the protection and use of existing germplasm collections; 3) identify and secure additional threatened diversity by developing and adopting suitable technologies and conservations strategies; 4) promote greater collaboration among research groups in producer countries and advance technology sources in the exchange of germplasm and the development of new conservation techniques; 5) conduct appropriate training, information dissemination; and 6) secure necessary funding for network activities. To achieve this goal, COGENT organized its Steering Committee (SC) with two representatives from each geographical region, the Executive Director of the APCC and the COGENT Coordinator who serve as non-voting members, with the latter also serving as SC Secretary. Five sub-regional/regional networks were also organized: South Asia; Southeast and East Asia; South Pacific; Africa and the Indian Ocean; and Latin America and the Caribbean. Each member country designates an experienced coconut scientist as COGENT Country Coordinator to coordinate COGENT-supported programme =in the country, and a Project Leader for every COGENT-supported project or activity that the country undertakes.

IPGRI continues to be the executing agency for COGENT and provides funding for the secretariat and technical and administrative support. The SC decides on the priority research and training activities. In 1995, Dr Persley organized the CGIAR Coconut Support Group, comprised of donors and partner institutions, which reviews the identified priority projects of COGENT for possible funding support.

Achievements in the last 14 years

Capacity development

To strengthen the coconut research capability of COGENT member countries, the COGENT Secretariat and IPGRI have organized 39 country need assessment missions and conducted 41 workshops and meetings involving 994 coconut researchers to share information and technologies, discuss issues and common problems and opportunities and how to address them; conducted 40 training courses involving 765 participants from 41 countries; supported 274 research and training/capacity building activities in 30 countries; and led the establishment of the Global Coconut Research for Development Programme (PROCORD).

International Coconut Genetic Resources Database (CGRD)
To equip member countries with relevant information and technologies for coconut research, COGENT, in collaboration with Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and with funding from the French Government from 1996 to 2003, developed the CGRD. To date, it contains the passport and characterization data (including some molecular marker data and pictures) of 1416 coconut accessions worldwide (Table 2). CIRAD has incorporated in the CGRD and its associated software, a management system endowed with functions that can be used to carry out all the necessary operations on the data it contains. Individual countries can now update their database as they generate data from their genebank collections. This database helps coconut breeders to effectively select materials for developing improved varieties.

Conservation in national coconut genebanks
World coconut production is declining due to ageing palms, natural calamities, inadequate replanting programme, lack of suitable planting materials, poor crop management, population pressures causing crop shifts, and lack of capital for farmers to invest in coconut production. The development and use of improved coconut cultivars can markedly help solve these problems and promote increased coconut production. However, the landraces of coconut (ecotypes), which contain important genetic characters for yield, disease and pest resistance and adaptation, are under treat to genetic erosion and need to be collected, conserved, evaluated and shared more widely to develop improved varieties.

Under the Asian Development Bank (ADB)-funded project (1998-2000), an additional 541 coconut populations were collected in 20 Asia Pacific countries and these were conserved in 16 national coconut genebanks. The conserved accessions are currently being evaluated and characterization data are registered in the CGRD.

Globally, COGENT supported member countries and partner institutions to conserve and upgrade 1416 accessions in national coconut genebanks and collections in 28 sites in 23 countries (Table 2). These collections include coconut genetic resources collected in respective countries and introduced from other countries which have potential use in developing improved varieties. Some of these germplasm have important traits for the production of high-value products or for the development of high-value varieties, i.e. high-oil content, aromatic, good tendernut flavor, soft-endosperm, high-sap content, big-sized nut, thick shell and high-husk content, and resistance to drought and diseases. It is imperative that these varieties are conserved on farm and used, as they are the basis for sustainable coconut production.

Table 2. COGENT's International Coconut Genetic Resources Database

Site	No. of accessions	25<P≤75	25<E≤75	With pictures	With molecular data
CNRA Marc Delorme Research Station, Port-Bouët, Côte d'Ivoire	99	92	71	73	67
Coconut Programme, OPRI, Sekondi, Ghana	16		4	15	14
CRC, Sémé Podji, Benin	4	4	4	4	3
National Coconut Development Programme, Dar Es Salaam, Tanzania	72	71	69	35	33
AFRICAN REGION	***191***	***103***	***148***	***127***	***117***
Centro de Investigacion Cientifica de Yucatan, Merida, Mexico	20	20	1	1	2
Coconut Industry Board, Kingston, Jamaica	60	16	58	32	36
EMBRAPA, Aracaju, Betume-Brazil	16	16	16	10	10
LATIN AMERICA-CARIBBEAN REGION	***96***	***52***	***75***	***43***	***48***
BARI, Gazipur, Bangladesh	40	18	37		
Coconut Research Institute, Lunuwilla, Sri Lanka	78	78	64	5	10
CPCRI, Kasaragod, India	212	141	211	76	52
RS, Islamabad, Pakistan	32				
SOUTH ASIAN REGION	***362***	***237***	***312***	***81***	***62***
Cocoa and Coconut Research Institute, Rabaul, Papua New Guinea	3		3	5	30
Stewart Research Station, Madang, Papua New Guinea	54	31	54	3	2
Ministry of Agriculture, Nuku'alofa, Tonga	7		1	2	2
Saraoutou Research Station, Santo, Vanuatu	79	71	11	48	53
Taveuni Coconut Centre, Taveuni, Fiji	11	8	7	5	5
Olomanu Coconut Seed Garden, RS, Apia, Samoa	9		9	4	3
RS, Yandina, Solomon Islands	21	4	21	10	11
SOUTH PACIFIC REGION	***184***	***114***	***106***	***77***	***106***
Coconut Research Institute, Wenchang, China	17	15	17		14
Department of Agriculture, Sabah, Malaysia	45	23	30	23	19
MARDI, Hilir, Perak &Terengganu, Malaysia	44	34	39	40	38
Bone Bone Experimental Garden, Manado, S. Sulawesi, Indonesia	41	35	41		
Mapanget Experimental Garden, Manado, N. Sulawesi, Indonesia	74	74	45	14	17
Pakuwon Experimental Garden, W. Java, Indonesia	25	22	25	8	10
Sikijang Experimental Garden, Pekanbaru, Indonesia	30	30	30	3	5
Philippine Coconut Authority, Zamboanga, Philippines	224	221	219	194	51
Chumphon Horticultural Research Centre, Chumphon, Thailand	52	42	52	9	8
Dong Go Experimental Center, Ben Tre Province, Vietnam	31	30	16	9	8
SOUTHEAST ASIAN REGION	***583***	***526***	***514***	***300***	***170***
TOTAL FOR ALL REGIONS	**1416**	**1032**	**1155**	**628**	**503**

Since its establishment, COGENT has helped its member countries upgrade and evaluate their collections and the new accessions that have been collected under the auspices of the ADB-funded project. The publication of the COGENT Standardized Research Techniques in Coconut Breeding or STANTECH manual (Santos *et. al.* 1996) has greatly facilitated much desired order into the collections and the streamlining of their management. In the past, lack of well trained coconut researchers had hampered coconut germplasm conservation and use. This constraint was addressed through two STANTECH regional trainers' courses, which included several aspects of field genebank management.

Conservation in COGENT's multi-site International Coconut Genebank

While national coconut field genebanks are important sources of germplasm for exchange among COGENT member countries, there are many constraints needing attention. First, many countries do not have the capacity to maintain their conserved germplasm due to lack of economic and technical capacity. Second, many countries do not have the capacity to evaluate the agronomic performance of their germplasm and if ever there were evaluation trials, data obtained are often not comparable. Third, multi-country negotiations for obtaining germplasm are often difficult for national breeding programmes that would like to import germplasm that belong to several countries. Fourth, many researchers who may want to share their germplasm do not have the needed policy cover and their countries lack the facilities for ensuring the safe movement of coconut accessions.

To provide double security for conserved germplasm in national genebanks and to promote effective access and safe germplasm movement, the COGENT Steering Committee decided to establish a multi-site International Coconut Genebank (ICG) in 1995, consisting of regional genebanks hosted by India for South Asia, Indonesia for Southeast and East Asia, Papua New Guinea for the South Pacific and Côte d'Ivoire for Africa and the Indian Ocean. Negotiations are underway for Brazil to host the ICG for Latin America and the Caribbean (Rao and Batugal 1994). To date, 224 accessions have been conserved (Table 3). These collections are part of the international *ex situ* collections under the Undertaking on International Plant Genetic Resources. Memoranda of agreements for hosting the ICG have been signed by the hosting country governments, IPGRI on behalf of COGENT, and the Food and Agriculture Organization (FAO) of the United Nations serving as trustee.

The four host countries are currently importing additional germplasm from the member countries in their respective regions. These will be grown

Table 3. Germplasm conserved in the International Coconut Genebank

Name of Genebank	Date when MOA signed	Initial number in list of designated germplasm	Designated germplasm currently conserved*
1. International Coconut Genebank for the South Pacific (Papua New Guinea)	30 September 1998	55	50
2. International Coconut Genebank for Southeast Asia (Indonesia)	26 May 1999	52	29
3. International Coconut Genebank for Africa and The Indian Ocean (Côte d'Ivoire)	14 October 1999	49	99
4. International Coconut Genebank for South Asia (India)	30 October 1998	49	46
Total		**205**	**224**

**Additional accessions were added to the initial list of designated germplasm.*

in vitro in the embryo culture laboratory, raised in the nursery and transplanted in the ICG when ready.

It is envisioned that the ICG for each region will conserve in field genebanks about 200 important accessions. They are being established and managed by the national programmes under the oversight of COGENT and IPGRI. With funding from the ACIAR, IPGRI/COGENT has published a Manual on Germplasm Health Management for the COGENT's International Coconut Genebank (Ikin and Batugal 2004) which will serve as the guide for national genebank managers and the quarantine service in managing the ICG and the movement of germplasm worldwide.

ICG laboratories and facilities will also be developed and upgraded which will be used to further locate diversity, identify and eliminate duplicates, conduct disease indexing, process pollen and embryos for export, conduct cryopreservation and train coconut researchers from member countries in evaluating, conserving and using germplasm. Thus, the ICGs will be developed as Centers of Excellence as part of the IPGRI intiative on upgrading and capacity building of its partner institutions.

The conserved germplasm in the field genebanks is covered by a Material Transfer Agreement obliging each ICG to provide access to their conserved germplasm to all coconut producing countries, not to patent conserved germplasm and to pass the later obligation to third parties receiving the germplasm. The inclusion of coconut in the list of commodity crops under the International Treaty for Food and Agriculture will further accelerate the sharing of coconut germplasm among the COGENT member countries.

In situ and on-farm conservation

COGENT realizes that despite the intensive efforts on collecting and conserving coconut genetic diversity *ex situ*, the major part will remain *in situ*, in the yards or gardens of small-scale farmers, undisturbed tropical sea coasts and uninhabited islands. Many of these farmers' varieties are in danger of being lost resulting in genetic erosion of some of the most adapted and needed germplasm for sustainable coconut production. Thus, COGENT has developed a protocol for genetic erosion study and has pre-tested it in Sri Lanka, Thailand and Kiribati. Initial results indicated that the threats to genetic erosion, caused by urbanization, shifts to other more profitable crops, calamities such as drought, typhoons, pests and diseases, are real and need to be addressed.

In situ conservation had been previously proposed as a method for conservation as it has the distinct advantage of conserving already adapted germplasm that have naturally evolved in niche environments. COGENT has developed and implemented a diversity-linked 'Poverty reduction in coconut growing communities' (PRCGC) project that addresses both *in situ* and on-farm conservation through a farmer participatory approach (Batugal and Oliver 2004; Batugal and Coronel 2004; and Batugal and Oliver 2005). Under this project, three pilot coconut growing communities in each participating country tested the viability of four coconut-based income generating strategies: 1) production and marketing of high-value products from all parts of the coconut; 2) intercropping cash and food security crops; 3) livestock/fodder production; and 4) production and selling of high-quality coconut seedlings which are raised in community-managed nurseries. The community-managed nurseries propagate seednuts for on-farm conservation from identified local varieties which are selected based on farmer participatory rapid appraisal of community genetic resources (Eyzaguirre and Batugal 1998) and during coconut diversity fairs. Mother palms of these selected varieties are paint-marked for *in situ* conservation and as sources of seednuts for propagation. Each project participant in the 24 community pilot models is .encouraged to plant at least five seedlings purchased from the community-managed nursery per year. Introduced high-value varieties are also propagated in the same nursery to increase the coconut diversity. This ADB-funded project, which was successfully implemented in eight Asia Pacific countries (Bangladesh, India, Sri Lanka, Indonesia, the Philippines, Vietnam, Fiji and Papua New Guinea) from 2002 to 2004, produced 65 505 seedlings from 89 farmers' varieties which were conserved on farm. Initial results indicate that it is a sustainable 'conservation through use' strategy (see Annex 2 for list of national coconut research agencies, non-governmental organizations (NGOs) and CBOs that participated under the ADB-funded PRCGC project).

Developing strategies and technologies for germplasm conservation and use

Conservation in field genebanks is the most popular and practical method of *ex situ* conservation but it is expensive and requires a large land area that many national programmes do not have. Thus, COGENT is supporting the development of complementary conservation strategies and technologies. In 1997, COGENT supported the development of coconut *in vitro* embryo culture techniques to facilitate collecting and the exchange of materials between partners and make such exchange safe from pests and diseases. A workshop was organized in Albay, Philippines involving eight countries to discuss the status of coconut embryo culture technology and to develop a collaborative research to upgrade the technology (Batugal and Engelmann 1998). COGENT awarded research grants to 12 countries to upgrade the technology, and in 2001, participants met in a workshop in Merida, Mexico to report on the results of their findings (Engelmann and Batugal 2002). These research results are published and disseminated to coconut researchers worldwide.

For long-term conservation, preliminary experiments have led to the development of a cryopreservation protocol, which has been successfully applied to zygotic embryos of four different genotypes. COGENT has collaborated with the International Research for Development (IRD, formerly ORSTOM) and national partners in upgrading the cryopreservation technology and in conducting two cryopreservation workshops to train the coconut researchers on the updated technology. Five coconut researchers were trained in the cryopreservation course at the National Board for Plant Genetic Resources (NBPGR) in India in 2002 and another five in a similar course at IRD in Montpellier in 2003. All trainees were required to develop re-entry work plans to validate techniques learned using their local accessions and laboratories.

The potential of somatic embryogenesis as a tool to promote accelerated coconut germplasm conservation and use has been explored. If successful, it could be used to rapidly multiply identified parent materials to provide adequate number of plants for breeding or replanting by COGENT member countries. Mass propagation by means of somatic embryogenesis was studied and clonal plantlets were produced for some genotypes in a reproducible manner. However, this study, which was funded by the European Union and involving five major advanced laboratories, was initially limited by its low recovery rate of embryos. Nevertheless, the recent report of work on embryo culture of the Centro Investigacion

Cientifico de Yucatan (CICY) in Mexico at the Coconut and Oil Palm Biotechnology Meeting in Manila in April 2004 indicated substantial progress. Using improved techniques developed by CICY, it was reported that about 100 000 embryos could be produced from a single plumule. COGENT is arranging for this upgraded technology to be downstreamed to the ICGs, and funding is being sought for the conduct of a workshop to disseminate the upgraded technology for further validation and refinement.

There is a need to develop and use molecular marker methods to characterize coconut germplasm, identify key physiological and agronomic parameters and their interactions with the environment, and to tag the desired traits for breeding. This will increase their predictive value in breeding for high-yielding, adapted and high-value varieties. For this purpose, COGENT collaborated with CIRAD in developing molecular marker methods for studying coconut diversity which produced a microsatellite kit, which 10 COGENT member countries are now using to characterize their conserved germplasm and farmers' varieties.

Given these developments, it should not be long before these new technologies can be exploited to complement the field genebanks and *in situ*/on-farm conservation for the medium and long-term conservation of coconut.

Germplasm evaluation

In 2001, COGENT and BUROTROP supported APCC in conducting a survey on the performance of coconut hybrids and varieties, and farmers' varietal preferences in 10 coconut producing countries. The results showed that: 1) there are no universal hybrids, with each hybrid having their specific niches where it performs well; 2) hybrids performed better than traditional varieties under adequate rainfall and good soil conditions; 3) under optimum growing conditions and management, the coconut hybrids tested could produce up to 5 tonnes of copra per hectare per year compared to the 1-2 tonnes obtained from traditional varieties; and 4) farmers were not interested in high yields *per se* but also in other characteristics such as low input-requiring varieties and varieties with special characteristics for producing high-value products.

In 1999-2004, COGENT conducted a CFC-funded hybrid multilocation trial involving three African countries (Côte d'Ivoire, Benin and Tanzania) and three Latin American and Caribbean countries (Brazil, Mexico and Jamaica) to identify suitable hybrids and varieties for smallholders. Each of the six countries compared six common multi-site hybrids produced and shipped from Côte d'Ivoire with their local hybrids.

The imported test materials were four Dwarf x Tall and two Tall x Tall hybrids which have been proven to have good yield potential in other separate trials. Included in each country location trial are 4-8 promising local hybrids/ varieties as local control. The Government of Portugal funded a similar project involving the evaluation of the same six multi-site hybrid controls and four local hybrids in Mozambique. This brought to 38 the total number of test hybrids/ varieties (including both the local and imported hybrids) being evaluated, making this project the most comprehensive coconut hybrid trial worldwide.

The most important initial result of the project is the identification of 19 early bearing and potentially high-yielding new coconut hybrids. Nineteen out of the 38 coconut hybrids in the first trial started to flower and produce fruits in Brazil, Jamaica and Mexico in 2.5-3.0 years after planting compared to the seven years it would normally take for the traditional Tall varieties to reach the fruiting stage. On the other hand, flowering was not observed in the hybrids planted in Benin, Côte d'Ivoire and Tanzania during the same period. These results suggest that the drought in Africa and the generally drier conditions in that region compared to those in Latin America and the Caribbean had a negative effect on the early flowering of the hybrids. This germplasm x environment interaction could be verified with the vegetative and reproductive plant measurements, and biotic and abiotic data to be gathered and analyzed in the next five years. Based on the yield projection of the 19 fruiting hybrids on their fourth year, they have the potential to produce up to 5 tonnes of copra (dried kernel) per hectare per year at the peak of production (at 10-12 years) compared to the 1-2 tonnes of copra produced by the traditional coconut varieties. The results of this hybrid evaluation and other hybrid performance observations around the world are presented in the COGENT publication entitled, 'Coconut Hybrids for Smallholders' (Batugal *et al.* 2005).

Developing platforms for a wider research and development programme

The value of coconut conservation is not maximized unless appropriate platforms are developed to deploy COGENT's conserved germplasm to promote germplasm utilization. COGENT has documented the breeding programmes of member countries (Batugal and Rao 1998) and is currently developing a proposal for a globally coordinated coconut breeding programme. The breeding programme shall focus on the regional/global needs of COGENT member countries instead of merely those of individual countries and will adopt participatory plant breeding approach to incorporate farmers' varietal preference. Specifically, the programme initially aims to: 1) characterize conserved germplasm and farmers' varieties using morphometric and molecular techniques; 2) screen and identify ecotypes tolerant or resistant to the lethal yellowing disease and drought ; 3) improve yields for specific uses and adaptation; 4) develop varieties which are suitable for the production of high-value products from husk, fiber, shell, meat, water, wood and leaves; 5) develop technical support systems for national breeding programmes (i.e. information, pollen and embryo provision, etc.); and 6) provide a platform to promote the dissemination and use of the results of the above-mentioned coconut breeding projects to achieve socioeconomic and environmental impact. Ultimately, the programme should be able to significantly increase the choice of hybrid cultivars among coconut growing countries, by maximizing the use of available genetic resources for breeding purposes, and improve the quality of the planting materials for distribution to users or farmers.

To provide a wider R & D platform for the utilization of COGENT's conserved germplasm and to enhance the impact of COGENT's current and future outputs, IPGRI/COGENT, the APCC and the Bureau for the Development of Research on Perennial Tropical Oil Crops or BUROTROP initiated the establishment of the Global Coconut Research for Development Programme (PROCORD), a global alliance to coordinate and promote global coconut research. The formal launching of PROCORD in 2002 provided a mechanism for an integrated approach to coconut research for development initiatives worldwide as envisioned in the original priority areas of coconut research as identified by the CGIAR. In the implementation of PROCORD, the lead role for coconut genetic resources conservation and improvement, and socioeconomic and policy support were assigned to COGENT; for coconut-based farming systems and crop protection, to BUROTROP; and for processing and marketing, to APCC. Due to the dissolution of BUROPTROP in 2003, the Centre de Cooperation Internationale en Researche Agronomique pour le Development (CIRAD) took over the functions of BUROTROP in this global research alliance, bringing its experience, expertise and resources to enhance the program.

Strategic public awareness and publications

In its effort to help disseminate strategies, technologies, public awareness materials and other information to promote coconut conservation and use, COGENT has produced and disseminated strategically selected publications (see Oliver, this chapter). It has also regularly published the COGENT Newsletter to serve as the information medium for updating members about the COGENT current and future activities; and

Table 4. Project grants provided to COGENT member countries

Country		No of LOAs*	LOA funding (US$)	National funding (US$)
1.	Bangladesh	17	83 796	36 770
2.	India	28	158 475	150 625
3.	Pakistan	2	14 487	5 000
4.	Sri Lanka	26	137 453	64 835
5.	China	5	34 373	28 000
6.	Indonesia	26	179 850	178 672
7.	Malaysia	6	61 800	103 000
8.	Philippines	30	175 815	237 127
9.	Thailand	9	70 626	539 343
10.	Vietnam	20	137 356	83 104
11.	Fiji	12	88 785	131 106
12.	Papua New Guinea	20	111 189	300 371
13.	Samoa	5	55 000	52 581
14.	Solomon Islands	5	61 000	94 600
15.	Tonga	5	60 200	24 500
16.	Vanuatu	5	55 000	74 900
17.	Cook Islands	1	11 000	6875
18.	Kiribati	1	11 000	6875
19.	Marshall Islands	1	11 000	6875
20.	Tuvalu	1	11 000	6875
21.	Benin	4	39 083	25 000
22.	Côte d' Ivoire	10	310 590	96 566
23.	Tanzania	9	59 833	49 916
24.	Brazil	7	53 333	44 166
25.	Jamaica	7	45 583	36 583
26.	Mexico	8	57 333	48 666
27.	Cuba	1	5000	6350
28.	Ghana	1	1500	750
29.	Mozambique	1	11 500	6000
30.	Portugal	1	8250	4000
GRAND TOTAL		**274**	**2 121 210**	**2 450 031**

***LOA** - *Letter of Agreement of member country with IPGRI/COGENT indicating project terms, activities and funding* established and maintained the COGENT webpage (http://www.ipgri.cgiar.org/networks/cogent). COGENT also published a book on technical writing, seminar presentation, public awareness and proposal preparation, and distributed this to all COGENT member countries to help coconut researchers worldwide effectively write and publish and present the results of their research (Stapleton *et al.* 2004).

Technical and financial support to member countries and partner institutions

To support regional and global projects, COGENT and IPGRI provided funds and technical backstopping to national programmes and partner institutions in 30 countries (Table 4). This enabled them to conduct 274 research projects, trainings, meetings and workshop activities in support of research with regional and global significance. For these activities, COGENT/IPGRI and its donor agencies provided 46% (US$2,121,210) of the funding requirements and the national programmes, 54% (US$2,450,031).

Conclusion

The establishment of COGENT addressed the need for an internationally coordinated research programme on coconut genetic resources in support of the smallholder coconut farmers and the coconut industry. To ensure the sustainability of the programme, the member countries agreed to reciprocal access to germplasm, information and technology; sharing of resources to implement agreed activities; and to collaborate in solving common problems and promoting common opportunities. The public and private sectors have high expectations for COGENT to help improve coconut profitability in a sustainable manner and to provide benefits to the coconut smallholder farmers. These expectations have been partly achieved with many substantive achievements of COGENT since its establishment 12 years ago. Support of partner institutions and donors is strong. However, in the final analysis, the success of COGENT will depend mostly on the commitment and political will of the member countries to help themselves.

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Annex 1. Partner institutions in COGENT member countries

1. Coconut Research Institute (CRI), China
2. Indonesian Center for Estate Crops Research and Development (ICECRD), Indonesia
3. Malaysian Agricultural Research and Development Institute (MARDI), Malaysia
4. Department of Agriculture Planning (DAP), Ministry of Agriculture, Myanmar
5. Philippine Coconut Authority (PCA), Philippines
6. Horticulture Research Institute (HRI), Department of Agriculture, Thailand
7. Oil Plant Institute of Vietnam (OPI), Vietnam
8. Bangladesh Agricultural Research Institute (BARI), Bangladesh
9. Central Plantation Crops Research Institute (CPCRI), India
10. Pakistan Agricultural Research Council (PARC), Pakistan
11. Coconut Research Institute (CRI), Sri Lanka
12. Ministry of Agriculture (MA), Cook Islands
13. Ministry of Agriculture, Sugar and Land Resettlement (MASLR), Fiji
14. Ministry of Natural Resources (MNR), Kiribati
15. Cocoa and Coconut Institute (CRI), Papua New Guinea
16. Ministry of Agriculture and Primary Industries (MAPI), Solomon Island
17. Ministry of Agriculture and Forestry (MAF), Tonga
18. Division of Agriculture and Rural Development (DARD), Vanuatu
19. Ministry of Agriculture, Forest, Fisheries and Meteorology (MAFFM), Western Samoa
20. Institut National des Reserches Agricoles du Benin (INRAB), Benin
21. Centre National de Recherche Agronomique (CNRA), Cote d’Ivoire
22. Oil Palm Research Institute (OPRI), Ghana
23. Kenyan Agricultural Research Institute (KARI), Kenya
24. Société Sambava Voanio (SOAVOANIO), Madagascar
25. Instituto Nacional de Investigacao Agronomica (INIA), Mozambique
26. Nigerian Institute for Oil Palm Research (NIFOR), Nigeria
27. Ministry of Agriculture and Marine Resources (MAMR), Seychelles
28. Mikocheni Agricultural Research Institute (MARI), Tanzania
29. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Brazil
30. Corporacion Colombiana de Investigacion Agropecuaria (CORPOICO), Colombia

Annex 2. National coconut research agencies, non-governmental organizations and community-based organizations that participated in the ADB-funded Poverty Reduction in Coconut Growing Communities project

National Research Institute (NRIs)

1. Bangladesh Agricultural Research Institute (BARI), Bangladesh
2. Central Plantation Crops Research Institute (CPCRI), India
3. Coconut Research Institute (CRI), Sri Lanka
4. Indonesian Center for Estate Crops Research and Development (ICECRD), Indonesia
5. Philippine Coconut Authority (PCA), Philippines
6. Oil Plant Institute of Vietnam (OPI), Vietnam
7. Ministry of Agriculture, Sugar and Land Resettlement (MASLR), Fiji
8. Cocoa and Coconut Institute (CCI), Papua New Guinea

Non-governmental organizations (NGOs)

1. Banchte Shekha Foundation
2. Peekay Tree Crops Development Foundation
3. *Siyath* Foundation

Community-based organizations (CBOs)

Bangladesh

1. Bandabila Coconut Community, Bandabila, Jessore
2. Chandrapara Coconut Community, Chandrapara, Barisal
3. Banchte Shekha (BS) Coconut Community, Jamira

India

4. Ariyankuppam Commune Coconut Farmers Association, Ariyankuppam
5. Pallikkara Community Coconut Development Centre, Pallikkara
6. Vayalar Community Development Project, Vayalar, Kerala

Sri Lanka

7. Thuthipiritigama Entrepreneurship Development Society, Thuthipiritigama, Hettipola
8. Womens Savings Effort, Wilpotha
9. Dodanduwa Womens Collective, Dodanduwa

Indonesia

10. Kelompok Tani Kelapa Harapan Wori, Wori, Wori District, Minahasa Regent

11. Kelompok Tani Kelapa Momosad Nonapan I, Nonapan, Poigor District, Bolaang Mongondow Regent
12. Kelompok Tani Kelapa Huyula Huntu, Bongomeme/Huntu Bongomeme District, Donggala Regent

Philippines

13. Malapad Integrated Livelihood Cooperative, Malapad, Real, Quezon
14. Bahay Patol Agrarian Reform Beneficiaries Multi-purpose Cooperative, Caliling, Cauayan, Negros Occidental
15. Linabu Coconut Planters Association, Linabu, Misamis Oriental
16. Fleischer Estate Integrated marketing Cooperative, Old Poblacion, Maitum, Saranggani (associated CBO)

Vietnam

17. Hung Phong/Phong Nam Coconut Community, Hung Phong and Phong Nam, Giong Trom District, Ben Tre Province
18. Xuan Dong Coconut Community, Xuan Dong District, Tien Giang Province
19. Tam Quan Nam Coconut Community, Tam Quan District, Binh Dinh Province

Fiji

20. Tukavesi Development Association, Tukavesi
21. Belego Multiracial Farmers Association, Belego, Wailevo
22. Cicia Women's Group, Cicia Island

Papua New Guinea

23. Murukanam Community Association, Murukanam
24. Transgogol Community Association, Transgogol
25. Last Karkar Community Association, Last Karkar

The Coconut Research for Development Programme (PROCORD)

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Background

Coconut farmers, 96% of whom are smallholders (tending less than 4 hectares), are suffering because of declining farm productivity and unstable markets for their traditional coconut products which are copra (dried kernel) and coconut oil. On the average, coconut farmers earn a gross income of about US$150-$200 per hectare per year which income is below the poverty line. The problems include declining yields and farm productivity, pests and diseases, poor farm management practices, lack of improved varieties, inappropriate processing technologies, inadequate access to information and markets and lack of understanding of the socioeconomic problems of the coconut farmer. Inadequate funding and institutional support to enable the research community to effectively address the major problems and opportunities of resource-poor smallholder coconut farmers have also contributed to the suffering.

In the past 12 years, the Bureau for the Development of Research on Tropical Perennial Oil Crops (BUROTROP) and the Asian and Pacific Coconut Community (APCC) have identified several of these major constraints of the coconut growing countries, but due to inadequate and discontinuous funding, they could only address these problems in limited ways. Since its establishment by the International Plant Genetic Resources Institute (IPGRI) 14 years ago, the International Coconut Genetic Resources Network (COGENT) has effectively implemented its mandate to promote the conservation and use of coconut genetic resources to increase the income of smallholders. However, its mandate has been limited to genetic resources conservation and use. Cognizant of these constraints, in May 2000, BUROTROP in collaboration with COGENT, presented a proposal for the establishment of a global coconut research programme along the commodity chain approach (from production to consumption) which was favourably received during the meeting of the Global Forum on International Agricultural Research (GFAR) in Dresden, Germany. Subsequently, national programme representatives from 34 coconut producing countries who attended the International Coconut Conference/COCOTECH meeting in Chennai, India in July 2000 recommended that a well-coordinated and well-supported coconut global research programme be developed along the commodity chain approach to address the other research areas that seriously limited coconut productivity and income.

The four other priority research areas needing international support in addition to coconut genetic resources, as identified by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) in 1991, to be addressed by the proposed programme include: 1) control of diseases (lethal or otherwise) and pests; 2) productivity and sustainability of coconut-based agroforestry systems; 3) efficiency and added value in postharvest handling and utilization of coconut; and 4) the socioeconomic issues influencing farmers' participation in rehabilitation and replanting of crops. The proposal to support research in these areas was presented by IPGRI at the International Coconut Conference in Chennai, India on 17–22 July 2000. At that meeting the participants identified an initial research agenda partly based on the identified priorities selected by TAC for coconut research in 1991 and recommended that further consultations with stakeholders on programme content, organization and management be conducted by COGENT in collaboration with the APCC, the intergovernmental organization of 14 coconut producing countries, and BUROTROP, the French-based research organization dealing with coconut and oil palm. At the completion of the consultation process, positive endorsements have been received from IPGRI, the COGENT Steering committee, APCC and BUROTROP.

In June 2001, the APCC Executive Director, BUROTROP Board of Administrators and the COGENT Steering Committee recommended that COGENT's mandate be expanded so that it could lead the initial coordination of the proposed Coconut Research for Development Programme (PROCORD) with the following justifications: 1) There is a need to create a platform for a wider range of coconut research and development activities which could effectively utilize the present and future outputs of COGENT; 2) there is no technology and research funding support from the private sector for the needs of smallholder coconut farmers; 3) there is no international commodity centre to take care of international research beyond coconut genetic resources; 4) there exists a demonstrated network approach that has proved to be a cost-effective mechanism of implementing a coconut global research collaboration, i.e. the COGENT network which is coordinated by IPGRI effectively collaborates with NARS institutions which actually implement projects and a similar mechanism could be used to effectively implement an expanded global programme; 5) there is a request from national programmes and partner institutions for the CGIAR to enable IPGRI/ COGENT to lead the coordination of the programme; and 6) there is a need to provide an experimental model for the CGIAR to deal with the inter-disciplinary needs of projects affecting resource-poor farmers within the limited mandates of existing CGIAR centres. This approach has created an impact through COGENT and it could also create a similar impact in the four other priority areas of coconut research identified by TAC.

In recognition of the above, the four organizations (including IPGRI) have agreed that COGENT will initially coordinate the programme. As a follow up action, the COGENT Coordinator, BUROTROP Director and the APCC Executive Director met and agreed on the following activities to accelerate the establishment of the programme: 1) refine the priority research areas as identified in specific sessions of the COCOTECH meeting in Chennai; 2) identify stakeholders to be involved in the proposed programme; 3) identify prospective members to serve in a Steering/ Coordination Committee for the proposed global programme; and 4) identify possible members for the proposed technical working groups. In undertaking the above activities, the lead role for coconut genetic resources and improvement was assigned to COGENT; coconut-based farming systems and crop protection, to BUROTROP; and processing and marketing, to APCC.

In 2004, due to the dissolution of BUROTROP and in consultation with and agreement among the representatives of APCC, BUROTROP and COGENT, it was decided that the Centre de Cooperation Internationale en Recherche Agronomique pour le Development (CIRAD) will take over the functions of BUROTROP in PROCORD.

Goal and objectives

The goal of PROCORD is to improve the returns on coconut to coconut growing farmers, communities and countries. Its objectives are:

1. *Improve productivity* - To improve productivity of coconut through the development of improved coconut varieties, the control of pests and diseases, the development of coconut-based ecosystems, the improvement of processing techniques, the production of value-added coconut products, and the study of socio-economic and policy issues affecting the coconut sector;
2. *Strengthen partnerships* - To strengthen and stimulate partnerships among stakeholders of the coconut community to foster the more efficient identification and application of research results to the needs of coconut growers;
3. *Enhance information access and dissemination* - To enhance access

to information and promote the effective documentation and dissemination of research findings;
4. *Promote capacity building* - To generate training opportunities for researchers and technicians to improve their knowledge and skills and foster the development of centres of excellence in various aspects of coconut research and development; and
5. *Generate support* - To provide effective coordination of research and the generation of institutional and funding support for priority research areas of global significance.

Priority research areas

In the last 10 years, APCC, BUROTROP and COGENT have conducted consultations with their respective stakeholders to identify problems and opportunities and needed research priority research projects to address them. In 1991, the Technical Advisory Committee of (TAC) of the Consultative Group on International Agricultural Research (CGIAR) identified priority research areas that need international support. At the International Coconut Conference/COCOTECH meeting in Chennai in July 2000 which was attended by representatives from 34 countries, the participants reviewed the research priority areas identified by TAC in 1991 and recommended research topics to be considered under each priority area. These were further refined by representatives of APCC, BUROTROP and COGENT and will be updated periodically as needed (with CIRAD replacing BUROTROP). Individually and collectively, APCC, CIRAD, COGENT and national and international partners are already undertaking research in these areas. It will be the role of PROCORD to identify the gaps, update priority areas and integrate the various research aspects to promote greater impact.

The broad priority areas are:
1. Germplasm collecting, conservation, evaluation and improvement;
2. Socioeconomics and policy support;
3. Control of diseases and pests especially the lethal diseases;
4. Productivity and sustainability of coconut-based agro-forestry systems;
5. Improvement of the efficiency and value-added benefits in post harvest processing and utilization; and
6. Marketing.

The details of these research areas are shown in Annex 1.

Research projects to be undertaken under this collaboration will be regional and global in scope so that location- and situation-specific research projects will be addressed by national programmes which will be more suited and equipped to effectively undertake them.

Organizational structure

As agreed by the four organizations and their stakeholders, PROCORD will operate through a Coconut Stakeholders' Group, a Coconut Support Group, a Coordinating Committee and six Technical Working Groups. The membership and mandates of these groups are described below.

Coconut Stakeholders' Group – All interested Inter-Government organizations, coconut farmers' organizations, research and development organizations from the public and private sectors, companies utilizing coconut either in processing, manufacturing or trading and NGOs. The mandate of the Group is to discuss problems, opportunities and issues affecting coconut producers and users, and provide advice and support on how these concerns can be addressed through prioritized research projects.

Coconut Support Group – All duly designated representatives of donors, development organizations and coconut producing countries which contribute funding and institutional support to coconut research. The mandate of this Group is to review research priorities and research projects identified by the Coconut Stakeholders Group and by the Coordinating Committee and to encourage its members to provide funding and institutional support to specific priority projects and activities on coconut.

Coordinating Committee – The members are the Chair and Executive Director of APCC; the Chair of the Board of Administrators and Director of CIRAD; the Chair of the COGENT Steering Committee; and the COGENT Coordinator. The mandates of the Committee are to address the priorities identified by the Stakeholders' Group and the Coconut Support Group; and to coordinate the planning, monitoring, evaluation, reporting of and fund generation for priority research projects. It will be assisted by the PROCORD Coordinator and a Secretariat. The Chair of the coordinating organization of PROCORD serves as the Chair of the Coordinating Committee.

Technical Working Groups – Specialists in six priority research areas will constitute the Groups: 1) coconut genetic resources and improvement; 2) socio-economics and policy support; 3) agronomy and coconut-based farming systems; 4) crop protection; 5) processing; and 6) marketing.

The mandates of the Groups are to identify priority research areas, develop priority regional and global project proposals on a competitive basis for submission to the Coordinating Committee and recommend the experts and institutions to undertake the work. The priorities and project proposals are submitted to the Coordinating Committee for review and endorsement to donors.

Programme coordination

APCC, CIRAD and COGENT may decide to rotate the coordination of PROCORD. The coordinating organization will provide the Secretariat and chairs the Coordinating Committee. COGENT coordinated PROCORD from 2002 to 2004. At the 13th COGENT Steering Committee meeting on November 2004, the three organizations approved the continuation of the coordination of PROCORD by COGENT.

Since PROCORD is being coordinated by COGENT, the COGENT Coordinator also serves as the coordinator of the programme and is responsible to the Coordinating Committee; IPGRI through COGENT provides the Secretariat and administrative support for the programme.

The six programme areas have been assigned to APCC, CIRAD and COGENT as their lead responsibilities: COGENT: 1) Genetic resources and improvement, 2) Socioeconomics and policy support; CIRAD: 3) Agronomy and coconut-based farming systems and 4) Crop protection; and APCC: 5) Processing and 6) Marketing.

Although two research areas are assigned to each institution, this does not mean that each organization will be limited in mandate only to these assigned research areas in PROCORD. Their total mandate and research activities are decided by their policy bodies, i.e. Steering Committee and IPGRI for COGENT; Board of Administrators for CIRAD and the Session for APCC. Any of the three organizations can thus conduct research in any of the six areas, consistent with the decisions of their respective policy bodies. However, for PROCORD, their main responsibility will be to coordinate the two research areas they are assigned to lead. They should thus lead in the development and coordination of PROCORD projects in their assigned research areas, based on the identified priorities of the Stakeholders' Group and the Coconut Support Group which will be fleshed out by their respective Technical Working Groups and endorsed by the Coordinating Committee. They could submit proposals and serve as executing agencies for these projects for their respective organizations. The proposed PROCORD Coordinating Committee will thus integrate and coordinate the work in the six areas to ensure that there is no unnecessary duplication of work, and that there is complementation and synergy of activities and sharing of resources.

Meetings

PROCORD will adopt the COCOTECH meetings as one of the venues of its stakeholders meetings and may have other complementary meetings as needed. The COCOTECH meets annually with representatives of government and non-governmental organizations and the private sector from 20-30 countries attending.

The CGIAR Coconut Support Group meets annually to review activities and priority research areas for coconut. The CGIAR Coconut Support Group annual meetings serve as the annual meetings of the PROCORD Coconut Support Group.

APCC, CIRAD and COGENT have joint meetings annually. Any of these joint meetings can be arranged so that the PROCORD Coordinating Committee can meet annually. This way, the Coordinating Committee could meet annually using existing resources.

Each of the three organizations can arrange for their respective Technical Working Groups to meet in coordination with their organizations' annual meetings or allied functions.

Launching of PROCORD and meeting of the Coordinating Committee

The programme was officially launched during the COCOTECH meeting of the APCC in Pattaya, Thailand on 5 July 2002 which also served as the first PROCORD Coconut Stakeholders' Group meeting. During the launching, a Memorandum of Agreement was signed by the respective Chairpersons of APCC, BUROTROP and COGENT and the Director General of IPGRI which spells out the details of collaboration among the three organizations implementing PROCORD. At this meeting, the priority research areas of PROCORD were presented. Immediately after the launching, the PROCORD Coordinating Committee held its first meeting.

Annex 1. PROCORD priority research areas

Germplasm collecting, conservation, evaluation and improvement

Support the conservation, evaluation and utilization of coconut genetic resources by:

- Collecting and conserving genetic resources, especially through the international coconut genebanks
- Developing effective strategies and techniques for conservation and the safe international exchange of germplasm
- Promoting inter-country exchange and evaluation of germplasm using common methodologies
- Developing new biotechnologies to shorten the breeding cycle and introduce useful new characteristics
- Establishing a global breeding scheme and support
- Developing a range of improved planting materials with a wide genetic base and consumer acceptability available to NARS and farmers

Socioeconomics and policy support

Identify the socioeconomic constraints affecting the coconut industry and developing opportunities for improving farmer productivity by:

- Identifying social and economic constraints to participation by smallholders in replanting and/or rehabilitation programmes
- Understanding the factors affecting adoption/non-adoption of new technologies
- Identifying and addressing market constraints and opportunities
- Identifying institutional development needs
- Developing poverty reduction strategies in poor rural communities
- Addressing policy constraints and recommending needed policy regulations
- Identifying and promoting the health, nutritional and environmental benefits of coconut

Control of diseases and pests especially the lethal diseases

Obtain the necessary basic scientific information to control major lethal diseases by:

- Identifying the causal agents of lethal diseases of unknown etiology in Asia, Africa and the Americas
- Improving diagnostic techniques for phytoplasmas
- Indexing protocols for virus/viroid diseases to facilitate the safe international exchange of coconut germplasm
- Epidemiological studies of lethal diseases, transmission

mechanisms, insect vectors
- Developing improved resistant varieties

Foster integrated pest management by:
- Developing cultural practices which favour integrated pest management
- Conducting surveys and inter-country exchange of natural enemies against major pests
- Identifying improved strains of viral and fungal pathogens for biological control.

Productivity and sustainability of coconut-based agro-forestry systems

To understand the principles of coconut-based ecosystems which govern the following:
- Functioning and physiology of the coconut agro-system
- Nutrient supply, through nutrient recycling
- Light interception and carbon balance, through adjusting tree density to maximise light use by intercrops
- Water relations, through interaction between coconut and its intercrops
- Multi-storey systems, to understand the principles of successful multi-cropping

Improvement of the efficiency and value-added benefits in post harvest processing and utilization

To improve the efficiency and quality of copra and coconut oil production, and increase the added-value on coconut processing by:
- Improving small-scale processing methods for copra and coconut oil production
- Improving fruit processing for large-scale users
- Increasing quality of value-added products such as desiccated coconut, coconut cream, coconut water, shell and stem
- Increasing the uses, quality and value of by-products derived from the kernel, husk, shell, sap, leaves and stem.

Marketing

To enlarge and diversify markets and promote consumption and use by:
- Conducting market studies to identify regional and global markets for major traditional and non-traditional coconut products (demand, prospects, consumer preference, utilization pattern)
- Developing market channels and strategic marketing techniques for coconut products

- Promoting the use of coconut in the food and non-food commercial and industrial sectors
- Conducting world product exhibitions and trade fairs for coconut products
- Promoting public awareness on coconut including coconut as health food e.g. through brochures and promotional materials

Chapter 8

COGENT's regional network reports

Research on coconut genetic resources in the South Pacific

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Introduction

The South Pacific Island nations are collectively one of the major producers and exporters of copra. Copra and coconut products continue to be important commodities for both the local and export markets, earning for these countries substantial foreign exchange. Coconuts are also important for household food security and the many uses of coconuts make them an essential part of life in the Pacific. Moreover, the environmental benefits of coconut palms are vital in maintaining the fragile ecologies of the Pacific Islands. Coconut trees prevent soil and beach erosion, recycle soil nutrients, act as windbreaks to prevent wind erosion and reduce the effect of typhoons and/or cyclones, and also provide shade to reduce soil temperatures.

Constraints and opportunities

Historically, coconuts have played an important role in the economic development of the region. The early trade and investment in the region was largely based on coconuts. However, the coconut boom ended with the decline in the copra prices, which lead to the neglect of coconuts. Since the drop in copra prices in the international markets, many coconut plantations in the Pacific have not been maintained and senile trees have not been replanted in many places. In addition, the high cost of transport from remote islands to export markets increases costs for exporters. Coconuts have also been felled to make way for other high value crops and fruit trees. In some remote islands, coconuts are still the main source of cash income, but with the low and unstable price of copra, incomes and living standards for those dependent on the crop have generally declined.

In addition to economic constraints, pests and diseases are considered threats but not a major concern in most areas. There are also limitations in government support policy and human resources devoted to coconut development. This is compounded by the lack of training and development support for the coconut industry.

Given the above constraints to developing the coconut industry in the South Pacific, there is a need to:

1. Focus on coconut-based farming systems to make possible intercropping and replanting of coconuts;

2. Develop new and encourage traditional coconut value-adding opportunities for households, import substitution, tourist markets and export;
3. Adopt new coconut cultivars specifically suited for specialty markets like tender green coconuts;
4. Establish national coconut development committees consisting of public and private sector; and
5. Train staff for coconut research and development activities.

Coconut research and development activities/ outputs in the South Pacific and their significance

The projects and activities of the IPGRI's (International Plant Genetic Resources Institute) International Coconut Genetic Resources Network (COGENT's) in the region in collaboration with the Centre Institut de Recherche pour le Développement (CIRAD), the Asian and Pacific Coconut Community (APCC) and the Bureau for the Development of Research on Perennial Tropical Oil Crops (BUROTROP), with funding from the International Fund for Agricultural Development (IFAD) and the Asian Development Bank (ADB), complement and strengthen existing national coconut programmes. The Pacific countries included in the projects are Fiji, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu. In recent years, valuable and threatened coconut germplasm have been collected from the Cook Islands, Kiribati, Marshall Islands and Tuvalu. Though many countries have continued to work individually on coconuts, COGENT's projects which integrate technical advice, training and logistical support have been vital in providing concerned government agencies in the Pacific countries with funding and support that would not otherwise be available. This support has been a catalyst for action on coconuts in the region that is much appreciated.

The Secretariat of the Pacific Community (SPC) is a regional technical organization which is the focal point for many networks in the region, including plant protection and quarantine, animal health, bananas, yams, and taro, just to name a few. Similarly, the SPC is a key part of the coconut network for the South Pacific. There is a strong rationale for a collective regional approach to coconut development through SPC, IPGRI/ COGENT, CIRAD, APCC, and BUROTROP.

The focus of COGENT in the Pacific has been on two regional projects and support for the International Coconut Genebank (ICG) in Papua New Guinea. The funding provided by these projects exceeds US$ 450 000, with counterpart funding by the participating countries exceeding US$ 650 000. Currently, there is the ADB- funded project on 'Developing

Sustainable Coconut Based Income Generating Technologies in Poor Rural Communities' that is being implemented in PNG and Fiji.

The other ADB-funded project 'Coconut Genetic Resources Network and Human Resources Strengthening in the Asia and Pacific' has been carried out in Fiji, PNG, Vanuatu, Samoa, Tonga, Solomon Islands. In addition, some activities have also been initiated starting in 1999 in Cook Island, Kiribati, Marshall Islands and Tuvalu. Ethnic conflicts in the Solomon Islands have inhibited the implementation of the project activities since late 1999.

These projects are significant because funding, training and technical assistance have been provided to national coconut researchers to undertake vital R&D activities based on the local needs and opportunities. In this way, the project outputs provide a basis for the implementation of effective strategies for the coconut industry development in the region.

Coconut germplasm collecting and characterization

Coconut germplasm was collected and partially described in the small island atoll countries of Cook Islands, Kiribati, Marshall Islands and Tuvalu by Jean-Pierre Labouisse and Dr Roland Bourdeix of CIRAD. This innovative regional activity was carried out under the auspices of the ADB-funded Coconut Genetic Resources Network and Human Resources Strengthening in Asia and the Pacific Region (CGRNAP) project of COGENT, which started in 2000 and completed in 2001. Under the project, coconut embryo cylinders were excised and transferred to the Regional Germplasm Centre of SPC. The coconut embryos were grown *in vitro* and then transferred to the ICG in Papua New Guinea in December 2000 and February 2001. The losses (mortality of embryos) were quite high because of a variety of reasons but the lessons learned from this activity will help in the future movement and exchange of coconut germplasm in the Pacific region. This was followed up with a Coconut Embryo Training Workshop in February 2001 at the SPC's Regional Germplasm Centre, Fiji to provide the skills needed to facilitate the movement of germplasm to the ICG-South Pacific. Other significant activities carried out in the region, by country, include the following:

- **Fiji:** Twenty-one (21) high-yielding local varieties were identified in farmer's fields. Eight new local varieties were collected in the last three years and planted in the field. Two cultivars from the Lau group were described, collected and planted at the Taveuni Coconut Center because they were in danger of being lost due to genetic erosion. One of the cultivars bears 50-cm long, thick-husked, elongated nuts, while the other variety yields 35 nuts per bunch that contain very sweet water.

- **Papua New Guinea:** The Cocoa and Coconut Research Institute (CCRI) has implemented a countrywide survey in which local germplasm were identified, collected and conserved in a field genebank located at the Institute's Stewart Research Station near Madang. The survey was carried out to identify local varieties that are resistant or tolerant to insect pests as a result of natural selection.
- **Solomon Islands:** During recent explorations, three distinct varieties have been identified (one Dwarf and two Talls). One of the local Talls identified is locally known as "Pine" and has a soft sweet husk which could be extracted by just using one's teeth and chewed like the fruit of the Areca palm.
- **Tonga:** Twelve ecotypes have been collected and planted in the collection plot. Four cultivars from the Vava'u group and three varieties from other Tongan islands have been collected, characterized and sown in the nursery.
- **Samoa:** A 1.22 ha coconut germplasm conservation site containing 11 local coconut varieties has been established.
- **Vanuatu:** A total of 87 coconut varieties have been identified in farmer's fields with 100 uses documented. So far, Vanuatu has contributed 65 accession entries to the International Coconut Genetic Resources Database (CGRD), composed of 18 exotic Talls, 18 local Talls and 29 Dwarfs.

In total, coconut germplasm collecting, characterization and conservation efforts in the Pacific have resulted in information gathered for the CGRD with passport data on 170 accessions and characterization data on 84 accessions. Data gathering for additional entries is ongoing.

Enhancing the National Agricultural Research System's (NARS) capacity in participatory technology development in coconut conservation and utilization

Using farmer-based Participatory Rural Appraisal (PRA) techniques, indigenous knowledge (IK) has been documented on certain coconut varieties and their multi-purpose uses. To expand public awareness on these IK, plans are underway to produce posters which would be distributed to all South Pacific countries. Regarding the documentation of IK, the following activities were implemented:

- **Fiji:** PRAs were conducted in six locations: in three villages on Vanua Levu, two in the Lau group and one on Bua. Many uses of coconuts were revealed including rope-making and the production of vinegar from fermented coconut water, which is also used to preserve chillies. On the island of Komo, the primary source of income is making fans from coconut husks. One of the major findings of the PRAs was that the lack of knowledge of local varieties, particularly by new generation farmers, was a factor contributing to genetic erosion as palms are continuously being felled to make way for other high-value crops, while old and senile palms are not being replaced by new, high-yielding varieties. Knowledge dissemination and *in situ* conservation are being implemented to alleviate this problem in several locations.

- **Vanuatu:** Eight PRA surveys were conducted in seven islands, resulting to the documentation of substantial information about local names and uses of coconuts as well as the different coconut-based farming systems. A total of 87 farmer's varieties were identified and about 100 different uses have been documented. In these studies, it was found out that the most common constraint facing coconut farmers in the islands was the high transport cost due to the long distance to markets as well as the bulkiness of the product.
- **Samoa:** PRAs were conducted in five villages on Upolo and Savii where five farmer varieties were identified and 30 multiple uses of coconuts in farm households were documented. The local Tall 'Nui Samoa' was identified as the most popular because of its high yield, quality copra and sweet juice, though another variety, 'Niu Kafa', was cited for its use in producing fibre-based products, particularly sinnet.
- **Tonga:** PRAs were conducted in three districts where farmers identified 14 local coconut varieties. Farmers preferred the local Tall Nui Tonga because of good yield and cyclone resistance. Multiple uses of coconuts identified included baskets, rope, buttons, firewood, lumber and roofing. Tonga is known for high quality handicrafts made largely from the various parts of the coconut palms.

Research on improving the income-generating potential of coconut production systems and increasing the yields of local varieties and hybrids

Vanuatu: Analysis of the coconut fruit of different hybrids and local varieties were undertaken. The protocols and methods for oil content analysis and oil extraction were refined. Fruit content, water, oil, and fresh albumen analyses were conducted on five varieties and hybrids. Initial results indicated that four varieties and hybrids gave higher copra yields per nut than the local Vanuatu Red Dwarf.

Fiji: Trials are being conducted to compare the performance of the local Fiji Tall with the hybrid progenies of MRDxRT, MRDxRIT, MYDxRT and MYDxRIT.

PNG: Sixteen (16) hybrids are under evaluation for yield, early bearing, and high oil content.

Enhancing incomes from high-value alternative coconut products and suitable varieties

In Fiji, a survey of the entire marketing channel, including export markets, for tender nuts was conducted. Results of the survey showed that there is a promising market for tendernuts. Preferred local varieties for tendernuts were determined and *in situ* conservation sites for the varieties established. Analysis of the chemical properties of the coconut water was undertaken for seven varieties.

Other coconut products

The cost and return analysis and the studies on socioeconomic benefits have been completed for coconut chips and coconut fudge in Fiji.

Coconut-Based Farming Systems (CBFS)

Samoa: A survey evaluating coconut-based farming systems indicated that the following are increasingly being intercropped with coconut: bananas, giant taro (*Alocasia macrorrhiza*), taro (*Colocasia esculenta*), cocoa, kava, yams, vegetables, and fruit trees. At the Nu'u Research Station, 14 types of fruit trees are being intercropped with coconuts to determine their suitability for CBFS.

Tonga: A survey of CBFS indicated the gross income of several intercrops including taro, sweet potatoes and tomatoes.

Summary of technical assistance/expert advice extended to all the South Pacific sub-network of COGENT

1. Malcolm Hazelman, SPC-Assessment of R&D opportunities and constraints, 1994
2. Gerry Santos, PCA - Assessment of R&D opportunities and constraints, 1994
3. Malcolm Hazelman, SPC, and Gerry Santos, PCA - Site identification for the ICG-SP
4. Gerry Santos, PCA - Project identification, 1997
5. Erlinda Rillo, PCA-Evaluation of the coconut embryo laboratory and staff training at ICG-SP, 1999
6. L Baudouin, R Bourdeix, and J Ollivier, CIRAD-Evaluation of

COGENT collecting strategy, identify gaps and recommend ways to improve coconut conservation
7. Robert Ikin, Quarantine Specialist - Pest Risk Assessment for movement of coconut germplasm to the ICGs, 1999
8. Roland Bourdeix, CIRAD - Assistance to Cook Island and Tuvalu for coconut germplasm collecting, characterization, conservation, and transfer to the ICG, 2000
9. Jean Pierre Labouisse, CIRAD - Assistance to Kiribati and Marshall Islands for coconut germplasm collecting, characterization and conservation and transfer to the ICG, 2000
10. Juan T Carlos, PCA - Cost and return protocols, 2001
11. Roland Bourdeix, CIRAD - Documentation of conserved germplasm in PNG, Samoa, Fiji, Tonga and Vanuatu, 2001
12. Jean Pierre Labouisse, CIRAD - Coconut germplasm documentation at the PNG ICG-SP, 2003
13. Pons Batugal, COGENT Coordinator - Bi-annual visits to the South Pacific sub-network member countries for a review of project, technical advice, and consultation on development of new projects

Summary of human resource development training workshops in the South Pacific sub-network of COGENT

1. Coconut Germplasm Collecting and Conservation Course, Philippines (1996)
2. Coconut Value Adding Workshop, PCA, Philippines (1997)
3. Regional STANTECH (Standardized Coconut Breeding Research Techniques) Course for South Pacific (1996 and 1999)
4. Farmer Participatory Research on Coconut Diversity (1998) (14 participants representing five South Pacific countries)
5. Computer use, Documentation and Data Analysis (1998)
6. Technical Writing/Seminar Presentation and Proposal Writing Course, Philippines (1999)
7. Coconut Data Analysis Course, Philippines (1999)
8. The ADB/IFAD funded project regional review meeting in Apia, Samoa to share project outputs and presentation from seven Pacific island countries (26-30 June 2000)
9. Coconut Embryo Culture Training Course, SPC Regional Germplasm Centre, Fiji (26- 28 February 2001)
10. Workshop on Coconut Genetic Resource Management and Using Microsatellite Kit and Dedicated Software, Montpellier, France (2002) (PNG only)

The International Coconut Genebank for the South Pacific (ICG-SP)

In Papua New Guinea, the Cocoa and Coconut Research Institute (CCRI) is the institution mandated to carry out coconut research. The Stewart Research Station of CCRI, located at Murunas in Madang Province, conducts breeding and evaluation studies, as well as agronomy and entomology research. CIRAD has played an important role in the establishment of this research centre with staff, training, technical assistance and funding. In 1998, the Memorandum of Understanding (MOU) establishing the ICG for the South Pacific (ICG-SP) in Papua New Guinea was signed between PNG and IPGRI/COGENT, with the FAO as trustee. The Stewart Research Station hosts the ICG-SP for the conservation, evaluation and use of important germplasm from the South Pacific region. Substantial progress has been made on the establishment of the ICG including land clearing, renovation of the embryo culture laboratory, training local staff, establishment of local and Dwarf accessions. There are currently 41 local Tall, six local Dwarfs and five exotic Dwarf populations in the ICG that are being characterized. COGENT has played an important role in the establishment of the ICG with feasibility studies, funding for the tissue culture laboratories, a generator for the laboratory, and training.

The coconut embryo laboratory has been completed and it has received shipments of embryos of 14 accessions from the Cook Islands, Fiji, Kiribati, Marshall Islands, and Tuvalu. These accessions are being established in the screenhouse for planting in the field. Though this may seem to be a small accomplishment, it represents the first actual transfer of coconut germplasm from regional members to one of the ICGs under COGENT.

Vanuatu Agriculture Research and Training Centre (VARTC)

VARTC represents one of the centres of excellence for coconut research in the Pacific. The research programme at VARTC was previously managed and supported by CIRAD staff. However, management of VARTC has recently been turned over to the governmental though CIRAD continues to provide technical support and staff to the centre. Research works in VARTC include coconut breeding and genetic improvement as well as physiology of the coconut palm and optimization of the coconut-based farming system. The breeding research focuses on the improvement of the Vanuatu Tall x Rennell Island Tall (VTTxRIT) hybrid, which is productive, resistant to the coconut foliar decay (CFD) viral disease and has a good copra yield. In addition, the European Union (EU)-funded Pacific Regional Agriculture Programme Project Phase 2 on the 'Production and Dissemination of Improved Coconut Cultivars' was initiated in 1989. The project aimed to develop and test new coconut hybrids on station before the new coconut hybrids can be disseminated. For this purpose, 33 new hybrids were created by hand pollination while seven trials were successfully established from 1992-1996, covering an area of 46 ha with 7400 palms. Each trial consists of hybrids created from crosses between Dwarf cultivars and Tall indigenous cultivars of different countries in the region including Solomon Islands, Kiribati, Fiji, PNG and Samoa. The results of these trials will be incorporated into a database that will be useful to the region for the development of new and better hybrids.

SPC Biofuels Project

The SPC Rural Energy Programme has worked in New Caledonia and Fiji for the development and implementation of coconut biofuel projects in isolated island communities. These projects are actually an integrated development approach that includes electricity for the community, value adding activities coupled with the replanting of coconuts. With the decreasing prices of coconuts and the high price of fossil fuels, there is considerable interest in this area. Results have so far been encouraging. However, there have been pilot activities and the long-term sustainability is still being studied. In 2002, a CIRAD team visited the Federated States of Micronesia to determine if a pilot facility could be installed there. In connection with this, a meeting was conducted in late 2002, with the Energy, Agriculture and Planning Departments of the government, along with community leaders, expressing a strong interest to expand the biofuels project for energy and rural development.

Pacific Agricultural Plant Genetic Resources Network (PAPGREN)

An effective national and regional conservation and management strategy is needed for plant genetic resources for food and agriculture (PGRFA) coupled with an effective capacity for the implementation of the strategy. The network will build on the existing PGRFA networks in the region such as COGENT and provide a regional framework for PGRFA that will be sustainable. It is expected that coconut will emerge as a national and regional priority of the network and activities will be developed to strengthen national and regional capacity to undertake PGRFA and related activities.

Future directions

The impact of the previously discussed projects, both regional and national, has been significant. Most of the coconut germplasm of the Pacific have been collected, characterized and conserved. The ICG-SP has been established and some threatened germplasm have been transferred to the ICG-SP for conservation. Human resources capacity for coconut research and development has been improved through training, technical advice and funding for activities. Linkages have been improved among research, extension and the private sectors. Collaboration and information sharing within and outside the region have been strengthened. These accomplishments are quite remarkable for the Pacific and could not have been accomplished without the strong collaboration of international, regional and national partners in the South Pacific network of COGENT.

There is a strong interest in coconuts by all the Pacific Island countries. There is a high level of national activities on coconuts that include seednut production, processing, and local marketing of coconut products and export of coconut products. Regional organizations such as the SPC and the APCC are interested and committed to strengthening coconut development in the South Pacific. There are international organizations that share this interest and commitment to assist the Pacific, which include COGENT, CIRAD and BUROTROP. The coconut industry is changing and this requires that the coconut farmers and the private sector to change with it. It also means that the Pacific Island countries will need assistance in adapting to the change. To achieve this, a three-pronged strategy is needed:

1. Increasing coconut yield through selected, adapted and high-yielding local varieties and hybrids;
2. Increased income and food security through efficient coconut-based farming systems; and
3. Increased income by production and marketing high-value coconut products other than copra and coconut oil.

Value adding and producing a multitude of products from coconuts had strong roots in the Pacific. More attention needs to be focused on how traditional products could be made to better adapt for tourists and export markets. At the same time, new products need to be developed to augment farmers' incomes in the coconut producing islands of the South Pacific.

Coconut research and development activities are still quite weak in the Pacific. Training and technical assistance at the national and regional levels are needed to develop appropriate efforts to foster the development of the coconut industry. There is also a need for a full-time regional coordinator to oversee and move activities in the region forward. By strengthening national and regional efforts, a more sustainable South Pacific sub-network could be created. Through a stronger sub-network, the ICG-SP in PNG could become a more effective focal point for the exchange of useful germplasm within the region as well as with other countries in other regions.

A number of coconut research and development strategies have emerged in discussions among the Pacific island countries that will build on previous projects and activities to help small-scale coconut farmers increase their incomes and help alleviate their poverty. These concepts were presented in a paper to the COGENT Steering Committee in 2002. The components of future Pacific regional coconut research and development consist of the following:

- Value-adding;
- Coconut-based farming systems;
- Germplasm conservation and exchange;
- Indigenous coconut germplasm;
- Hybrid trials; and
- Synthetic varieties.

A partnership of national, regional and international organizations will be necessary to further develop these elements into concrete projects and activities with the assistance of COGENT, APCC and BUROTROP, possibly under the Coconut Global Research for Development Programme's (PROCORD's) umbrella. There is a bright future for small-scale coconut farmers in the Pacific if this direction is taken.

Research on coconut genetic resources in South Asia

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The South Asia (SA) sub-regional network of COGENT covers the countries of India, Sri Lanka, Bangladesh and Pakistan. After Southeast and East Asia, the South Asia region is the world's second largest producer of coconut.

Status of coconut genetic resources research

India

Importation and growing of designated germplasm from COGENT member countries for conservation in the International Coconut Genebank for South Asia (ICG-SA)

UnderPhase 1 of the Asian Development Bank (ADB)-funded project on coconut genetic resources and human resources strengthening for Asia and the Pacific region, 15 accessions were collected during 1997 as embryos from the Indian Ocean Islands of Mauritius (6 accessions), Madagascar (4 accessions) and Seychelles (5 accessions). Under Phase 2 of the same project, eight accessions were collected from Maldives, five accessions from Comoros and three accessions from Reunion Island during 2000. During February 2001, four accessions were collected from Sri Lanka. These exotic collections were made in the form of zygotic embryos and are being cultured in the laboratory.

It is envisaged that representative germplasm from India and other South Asian countries will be conserved in the ICG-SA and shared with other countries of the region. This project will strengthen the ICG-SA by supporting the importation of germplasm from member countries of South Asia for planting in ICG-SA.

Introduction of coconut germplasm from COGENT member countries into the ICG-SA (DFID-funded))

This project was an extension of the DFID Phase –1 Project on Improvement of *in vitro* techniques for collecting and exchange of coconut germplasm. Its objectives were:

1. Arrange with the COGENT member countries to send at least 300 embryos to ICG-SA;

2. Arrange for import and quarantine permits for the introduction of germplasm;
3. Grow the embryos *in vitro* using updated embryo culture protocol as agreed during 2nd International Coconut embryo culture workshop in Merida in 2000 or any suitable modifications;
4. Successfully transplant and acclimatize at least 120 embryo derived plants for each accessions and grow them until ready for field planting at ICG-SA.

Gemplasm collected as embryos from Bangladesh and Sri Lanka were *cultured in vitro* for obtaining plantlets for planting in the ICG-SA (Table 1).

Table 1. Number of embryo-retrieved plantlets transferred to ICG-SA for field planting in 2003

Country	No. of plantlets retrieved
Maldives	40
Comoros Islands	20
Reunion Island	7
Sri Lanka	118
Bangladesh	73
TOTAL	**258**

Developing sustainable coconut-based income generating technologies in poor rural communities in India

To help Indian coconut farmers, COGENT collaborated with the Central Plantation Crops Research Institute (CPCRI) in implementing the ADB-funded 'Poverty reduction in coconut-growing communities' project from January 2002 to December 2004. Three pilot sites were chosen: Pallikkare and Ariankuppam communities in Kerala State, West Coast Region; and Vayalar community in Pondicherry District, East Coast Region.

Farmers in the project sites were organized into community-based organizations (CBOs): Pallikkare Community Coconut Development Centre (PCCDC), Ariankuppam Community Coconut Farmers Association (ACCFA) and Vayalar Community Development Centre (VCDC). As a prerequisite to joining, Pallikkare and Ariankuppam farmers had to pay a one-time membership fee of Rs 50 (US$ 1.08), while those in Vayalar had to shell out Rs 109 (US$ 2.39). Officers were elected and the CBOs were subsequently registered with the concerned government agencies. As of project end in December 2004, there were 1642 active CBO members, all of whom had been trained in CBO/

cooperative and microcredit system management. With the help of CPCRI, the CBOs conducted market surveys to identify marketable products that the communities could produce, as well as markets where these could be sold. Based on the results of these market surveys, the communities developed farmers' and women's action plans for the duration of the project.

Aside from CBO and microcredit system management, farmers were also trained on seedling nursery management, coconut pests and diseases management, intercropping, livestock rearing and local feed formulation, production of kernel-based products (coconut candy, coconut chips, cookies, nata de coco, chutney powder, coconut oil, coconut soap and virgin oil), coconut water-based products (vinegar, tendernut and 'snow ball'), fiber-based products (ropes, doormats, geotextile, brush, coir dust for planting material and body scrub), shell-handicrafts (cutleries/ utensils), and marketing. Some were also trained on vermicomposting and mushroom production. A total of 3269 male and female participants have been trained, with some of them attending two or more training courses.

To help the project beneficiaries undertake income-generating activities, the project provided the CBOs with machineries, equipment and seed money (US$ 7200) for their respective microcredit systems, which was supplemented by the CBO membership fees. The microcredit system provided members with the needed capital and resources to purchase quality seeds or planting materials for intercropping such as pepper, banana, colocasia, cowpea, yam, fodder grass, turmeric, pineapple, cassava, vegetables, legumes, upland rice and others. The farmers also borrowed from the fund to buy high-yielding coconut seedlings from the community-managed nurseries and to procure livestock such as giriraja poultry, turkey, chicken, ducks and goats. In Vayalar, the interest rate for a member's loan is fixed at 10% per annum, with an interest discount of 2% for prompt repayment and a grace period of two months for commencing repayment. In Pallikkare and Ariankuppam communities, a minimal interest rate of 2% per year is charged against the loans of CBO members. As of August 2004, the total loan released to the three communities was US$ 12 860 and the amount recovered was US$ 5058, generating a repayment rate of 39%.

To enhance the communities' coconut germplasm resources, 15 community-managed seedling nurseries, involving 27 farmers, were established in the three sites. The seedlings raised in these nurseries came from seednuts of 15 local farmers' varieties that had been previously identified as suitable and desirable based on a farmer participatory characterization protocol undertaken during the farmer diversity fairs.

The mother palms of these selected varieties were conserved *in situ* and paint-marked for identification. So far, 5600 seednuts have been propagated and sold from these nurseries. CBO members have also planted 8800 new seedlings bought from these nurseries and those provided directly by CPCRI.

To supplement their farm incomes, 759 CBO members are currently involved in intercropping trials; 370 are engaged in livestock production; and 615 are into the production of diversified high-value coconut-based products. Of the total 1744 CBO members engaged in various income generating activities, 43% are women. CPCRI observed that these interventions have increased farmers' incomes by three to five times based on the average pre-project farm earnings of US $ 200/year.

To fully help the farmers, CPCRI sought the assistance of various partners, including: the Krishi Vigyan Kendra, Kerala Agricultural University, Department of Animal Husbandry, State Department of Agriculture, MS Swaminathan Research Foundation, National Bank for Agricultural Rural Development, District Cooperative Bank State Planning Board through the Kudumbashree Project and the Coconut Development Board. Assistance extended by these partners ranged from providing counterpart funding to providing resource persons for training and assisting in marketing.

Sri Lanka

Developing sustainable coconut-based income generating technologies in poor rural communities in Sri Lanka

With support from the Asian Development Bank (ADB), COGENT coordinated 'Poverty Reduction in Coconut Growing Communities' project is being implemented by the Sri Lanka's Coconut Research Institute (CRI) in partnership with three community-based organizations namely: Dodanduwa Womens Collective (DWC) in Dodanduwa, Galle, (Southern Province), Womens Savings Effort (WSE), in Wilpotha, Puttalam (Western Province) and Thuthtiripitigama Entrepreneurship Development Society (TEDS) in Hettipola, Kurunugala (Northwestern Province). All the CBOs are registered with Divisional Secretariat (Special Act for NGO) of the Government of Sri Lanka.

The three CBOs had a combined membership of 716 farmers and women. Over the two and half years of the project, around 1287 participants were trained on various income generating activities, on CBO and microcredit management and on nursery management, with some members attending two or more trainings. CBO and microcredit management shared the highest number of participants (529 or 41%) while only 5% of the participants were trained on nursery management.

A total of 328 CBO members have engaged in intercropping cash and food security crops with coconut. One hundred ninety five members are involved in: livestock production such as chickens, goats, cattle, quail, ducks; hatching eggs and selling chicks; selling cow's milk and milk products; producing feedcrops; raising honeybees; and growing mushrooms. Processing high-value coconut-based products such as coconut virgin oil, soap, cooking oil, handicrafts from coconut shell, fibers, leaves and bracts, and confectioneries involved 168 members. Around 90% of members involved in various income generating activities are women. . These activities raised their average per capita income earned during the period as of September 2004 by SLR 8000 to 8300 (US$80-83)

Six community-managed nurseries have been established, with an aggregate value of SLR 413 020 (US$4130). Around 9900 seednuts and a number of fruit trees and cash crops have been propagated in the nurseries. So far, more than 5510 coconut seedlings have been planted on farmer's field and home gardens.

The three CBOs total revolving fund is US$60 710, of which US$14 886 (25%) was loaned from the project, US$10 824 (18%) is members equity and US$35 000 (57%) derived from other external sources. The CBOs' microcredit system has so far loaned out US$32 000 to 538 member-borrowers. So far, recovery rate for the total loans released is 82%. The total combined assets of the CBOs amounted to SLR 7 369 000 (US$73 690).

The project through the CRI has published and disseminated six scientific papers, featured five articles in local newspaper, distributed three project fact sheets and conducted nine field days to increase public awareness on the opportunities of increasing productivity of coconut farming systems. The project staff had also presented activity-related papers in seminars, conferences and meetings.

The Poverty Reduction project enabled effective collaborating with over a dozen organizations, including local and international NGOs, government agencies, rural banks, religious organizations, academe and scientific society among others. The project strongly believed that other stakeholders have important roles to play to accomplish its objectives. These organizations have willingly provided technical support, planting materials, animalstocks, organizational management and entrepreneurial support, funds, facilities and equipment worth well over US$10 000.

The initial successes in the three pilot communities were well recognized by the adjoining villagers prompting them to join the CBO. The WSE, for example, has expanded its membership to include a resettlement area in Puttalum District and the DWC has expanded its membership to include 58 members from Karauwa and Mannagoda in

Pitigala, some 30km away from Dodanduwa. Government agencies are looking at the project with great interest for possible adaptation to help their *Samurdhi* programme beneficiaries to eventually survive on their own.

Bangladesh

Developing sustainable coconut-based income generating technologies in poor rural communities in Bangladesh

Bangladesh produces an average of 90 000 tonnes of coconuts annually from a land area of about 30 000 ha, comprised mostly of homesteads with an average area of 350 sq m. The country presents a special case in that the average coconut landholding could not even be considered as 'farms' but rather just 'plots', which is one of the main reasons Bangladeshi farmers remain poor. It is under this condition that COGENT, in coordination with the Bangladesh Agricultural Research Institute (BARI), implemented the ADB-funded 'Poverty reduction in coconut growing communities' project in 2002. The project aimed to demonstrate that even with small 'plots' of land, these coconut 'farms' could be made more productive and give farmers more income than they earned from copra.

In the first quarter of 2002, community-based organizations (CBOs) were established in each of the selected pilot communities: Bandabila Coconut Community in Bandabila, Jessore District; Chandrapara Coconut Community in Chandrapara, Barisal District; and Banchte Shekha (BS) Coconut Community in Jamira, Khulna District. These CBOs have been registered under the Social Welfare Department of the Government of Bangladesh. Farmers who joined the CBOs did not pay membership fees but they were required to compulsory 'save' US$ 0.17 a month, which goes to the members' individual accounts and can be tapped as a common funding pool. As of August 2004, the total CBO membership has reached 300. With the support of BARI, the CBOs conducted market surveys to identify potential marketable products that they can produce. Based on the results of these surveys, farmers' and women's action plans were developed.

The CBOs trained its members in various coconut-based income generating technologies. As of August 2004, a total of 4980 farmers and women participated in training on CBO and microcredit system management, nursery management, coconut pests and diseases management, livestock raising and local feed formulation, production of kernel-based products (coconut candy, cookies and virgin oil), fiber-based products (ropes and doormats), and product marketing.

As access to capital was one of the main constraints identified by the farmers, the project established a microcredit system and provided the communities with seed revolving funds in cash (US$ 7000) and in kind (machineries and equipment).. So far, a total of 300 farmer-members have benefited from small loans provided by the microcredit system for intercropping, livestock rearing and processing of diversified high-value coconut products. Loans have also been given to members for replanting old and unproductive coconut trees. As of August 2004, the total loan released to the three communities was US$ 6743 and the initial amount recovered was US$ 1547, or 23% repayment rate.

Integral to the project is the improvement of coconut genetic diversity in the pilot communities. To address this, nine community-managed seedling nurseries have been established in the pilot sites involving 300 farmers. Seedlings raised and propagated in these nurseries came from seednuts of 18 high-value and high-yielding local farmers' varieties that had been previously identified through coconut diversity fairs. The mother palms of these identified varieties were conserved *in-situ and* paint-marked for identification. In addition to maintaining and selling high-quality coconut seedlings, the nurseries also produce quality planting materials for intercrops. So far, 5100 seednuts have been propagated and sold by these nurseries, from which 3473 seedlings have been bought and planted by the CBO members on-farm.

To augment farm incomes, CBO members were encouraged to engage in various income generating interventions. Currently, 133 farmers are producing high-value coconut products like ropes, doormats, coconut oil and coconut candy; 115 farmers are into intercropping; while 178 farmers are raising chickens, ducks, goats and cattle under coconut. Recent surveys by BARI indicated that these interventions have increased farmers' incomes by three to five times based on their average pre-project earnings of US $ 12/year from their small plots.

BARI partnered with various public and private sector agencies in the country to effectively put in place a support system for the project. These include: the Directorate of Agricultural Marketing, Krishi Katha-Agricultural Information Services, The Daily Star Magazine, Department of Cooperative, Directorate of Livestock, Directorate of Agricultural Extension, Bangladesh Livestock Research Institute, Directorate of Livestock, Northwest Bangladesh Crop Diversification Project, Regional Agricultural Research Stations of BARI at Barisal and Jessore, On-Farm Research Division of BARI in Khulna, Department of Social Welfare at Khulna, Barisal and Jessore, and the Grameen Bank. Assistance provided by these partners included financial and technical support and advice, provision of resource persons for training, planting materials and animal stocks, public awareness and marketing.

Pakistan

Varietal selection

Although plantations of coconut have been in existence in Karachi for a long time, most of these are scattered and there is no organized plantation with known varieties. Efforts to plant coconut in organized plantations started in the late 1950s when groves were established in government farms, which continued for some time but with very little success. However, the survey conducted by national and international agencies proved that coconut can be successfully grown in the coastal belt of Sindh and Balochistan Provinces with proper management and constant irrigation as the areas are prone to drought and temperature fluctuations. The farmers in this area obtained seednuts from different countries, mainly from Sri Lanka, Bangladesh, India and Malaysia but very little or no attention was given to the specific variety, only that these are either Talls or Dwarfs. In the late 1970s, varieties with known cultivar names and characters were imported from Sri Lanka for evaluation. The activities were later organized by Pakistan Agricultural Research Council (PARC). After the evaluation, more varieties and hybrids were imported from Sri Lanka to be raised in government nurseries for distribution to farmers. The Sindh Forest Department was also involved in these activities, establishing their own plantation in forestlands near Thatta.

Results of the evaluation carried out by the two institutions recommended Tall varieties for planting as these were more tolerant to biotic and abiotic stresses and produce bigger nuts with better copra quality. Some farmers, though, prefer Dwarf varieties as they bear more fruits which are mainly used for coconut water and are easily marketed. However, Pakistani coconut farmers do not like the Sri Lanka hybrid as it was found to be easily damaged by stress due to conditions prevalent in the country. The MAWA hybrid, on the other hand, impressed some growers but could not be cultivated in larger areas because of similar problems.

Orchard management

Orchard management activities focused on finding the most effective and efficient fertilizer combination and requirement to grow coconuts productively. It was a general impression that the coconut does not require much fertilization and the growers used only Farmyard Manure (FYM) in households as well as field plantations. Later on, trials conducted proved that application of inorganic fertilizers improved the health of palms and decreased flower and fruit drop resulting in higher nut yield with better quality. The results of these trials proved that application of 250 g N, 100 g P and 200 g K per plant was beneficial and economical for improving growth, bearing and nut quality. Addition of FYM also proved beneficial for soil improvement particularly in slightly saline soils.

Irrigation was another important aspect under orchard management as areas planted to coconut received very low rainfall and frequently faced drought. Furthermore, many of these areas are characterized by sandy soils. To address this situation, it was recommended that crops be irrigated weekly during summer and fortnightly during winter.

It is a common practice in Pakistan to keep orchards clean and not to grow any intercrops after the trees start bearing fruits. Recent studies, however, concluded that it was possible to grow vegetables as intercrops in a coconut farm as they did not affect the growth of the palms as earlier believed and it was also proven to be a profitable venture to augment farmers' incomes.

Pests and diseases

Surveys were conducted in different coconut plantations to collect information about the existence of pests and diseases. Results of the surveys showed that the major diseases affecting coconuts in the country include root rot, bole rot, bud rot, leaf blight, stem bleeding and lethal yellowing. The intensity of these diseases greatly varied from place to place and was also found to be correlated with orchard management, with poorly managed plantations having more serious problems. Spraying of recommended dosages and combinations of fungicides satisfactorily controlled the spread of some of these diseases, except lethal yellowing.

The surveys also revealed the insect pests damaging coconut palms in the country, which includes termites, red weevil, scales, black beetle and coconut caterpillar. Initially, these pests were controlled by the use of appropriate insecticides. Surveys on the extent of damage and detailed studies related to the biology, epidemiology and control of these insect pests have not been conducted and need to be made in the future.

Very little or no work has been done on the production and marketing of alternative and high-value coconut products as overall yield was relatively small and farmers did not have problems marketing the nuts. The fruits are mainly used for coconut water and immature copra. The coconut leaves are used as roofing materials in mud houses while the stem has no known uses other than as firewood.

Research on coconut genetic resources in Southeast and East Asia

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Introduction

The Southeast and East Asian (SEEA) region produces more than half of the world's coconuts (Table 1), and among the members of the International Coconut Genetic Resources Network (COGENT), the Philippines and Indonesia have the largest collection of coconut populations (Table 2). Other countries composing the Southeast and East Asia sub-network are China, Malaysia, Myanmar, Thailand and Vietnam (Annex 1).

Country	Area (ha)	Copra Production (tonnes)	Export Value (US$ '000 000)
Indonesia	3 701 474	3 196 499	242.0
Vietnam	250 000	230 261	3.4
Malaysia	159 000	58 000	165.7
Thailand	327 000	61 210	13.9
China	70 000	67 403	not applicable
Philippines	3 100 000	1 475 000	352.6
TOTAL	**7 607 474**	**5 088 373**	**777.6**

Table 2. Number of accessions conserved in the Southeast Asian Region *(Source: COGENT Newsletter Issue No. 3, May 2000)*

Country	Conservation Sites	No. of Accessions
Thailand	Chumphon Horticultural Research Centre	52
Indonesia	Bone Bone Experimental Garden, South Sulawesi	41
	Mapanget Experimental Garden, North Sulawesi	65
	Pakuwon Experimental Garden, West Java	25
	Sikijang Experimental Garden, Riau Province	25
Philippines	Philippine Coconut Authority-Zamboanga	224
Malaysia	MARDI/Hilir Perak	44
	Department of Agriculture/Sabah	48
Vietnam	Dong Go Experimental Centre	31
TOTAL for Southeast Asia		**555**

Of the 11.9 million hectares of coconut grown in the world, eight million hectares, or about 70% is in Southeast and East Asia, with Indonesia and the Philippines together accounting for 90% of this hectarage. The Philippines has the largest coconut collection in the world and remains to be the foremost exporter of coconut oil in the world, while Indonesia has the greatest potential of having the widest coconut diversity in the region and possibly in the world. Thailand and Vietnam grow coconut only in some of their provinces and that multiple uses of coconut from its various parts (i.e. husk, shell and water) appear to be the main occupation of coconut entrepreneurs, particularly catering to the export markets. Malaysia is reportedly losing 3000 palms a year due to urbanization and replacement with oil palms. However, coconuts still play a crucial role in the lives of the Malaysian coconut farmers since Malaysia imports about 400 000 nuts a year for local consumption alone. On the other hand, China is slowly developing its coconut industry, its Hainan Island is home to some very interesting cultivars, specifically those that thrive in cold temperatures. Efforts to develop the island's coconut industry offer great prospects of marketing coconut and coconut by-products to mainland China.

Identification of the coconut varieties suitable for products with good market value is a must in genebank management. In 1992, the International Plant Genetic Resources Institute (IPGRI) through COGENT initiated the development of the International Coconut Genetic Resources Database (CGRD) in collaboration with the Centre de Cooperation Internationale en Recherché Agronomique pour le Développement (CIRAD). The database aimed to document and disseminate passport and characterization data on conserved germplasm, facilitate international information exchange and promote access to coconut varieties for the breeders and other users. The CGRD software enables members of COGENT to input their own data, access other members' data and share information.

Meanwhile the Coconut Data Management (CDM) software developed by CIRAD makes it possible to print cartographic representation of the palms in each field, enabling the display and modification of palm characteristic on a map. The software was introduced in a training course held in Montpellier in 2002. Included in the course is the introduction of a microsatellite kit for analyzing the DNA profiles of coconut germplasm in existing germplasm collections.

Status of coconut genetic resources and related research

Philippines

The Philippine Coconut Authority (PCA) genebank in Zamboanga is considered to be one of the most important germplasm repositories of local and foreign coconut ecotypes in the world, where 224 coconut accessions are being maintained. Eleven accessions are of foreign origin, such as the West African Tall (WAT), Rennel Island Tall (RIT), Gazelle Peninsula Tall (GPT), Markham Valley Tall (MVT), Vanuatu Tall (VTT), Karkar Tall (KKT), Malayan Red Dwarf (MRD), Malayan Yellow Dwarf (MYD), Equatorial Guinea Green Dwarf (EGD), Sri Lanka Green Dwarf (SGD) and Aromatic Green Dwarf (AROD). The introduced materials make it possible for the country to participate in the planned global coconut-breeding programme of COGENT.

Like other countries, Tall varieties dominate the areas planted to coconut. The major Tall populations grown in the country are Laguna (LAGT), Bago-Oshiro (BAOT), Baybay (BAYT), Makapuno (GUZT), San Ramon (SNRT), Tagnanan (TAGT) and Hijo Tall (HJT). The Dwarf varieties include Catigan (CATD), Tacunan (TACD), Kinabalan (KIND) and Aromatic (AROD).

Apart from the 11 introduced accessions, 22 are hybrid/line collections. The first three locally-produced hybrids, namely PCA 15-1 (CATD x LAGT), PCA 15-2 (MRD x TAGT) and PCA 15-3 (MRD x BAYT), were mass-produced using the assisted pollination breeding technique for the planting/replanting programme of the PCA. Other hybrids produced which were also registered with the National Seed Industry Council (NSIC) are PCA 15-4 (CATD x TAGT), PCA 15-5 (CATD x BAOT), PCA 15-6 (CATD x PYT), PCA 15-7 (MRD x PYT), PCA 15-8 (TACD x BAOT), PCA 15-9 (TACD x TAGT), PCA 15-10 (TACD x LAGT), PCA 15-11 (TACD x WAT), PCA 15-12 TACD x RIT), PCA 15-13 (MRD x LAGT), PCA 15-14 (MRD x BAOT) and PCA 15- 15 (CATD x BAYT). These hybrids were selected based on their outstanding and stable yield performance as well as economic profitability (Santos *et al.* 2000). Registered local Dwarf and Tall varieties are CATD, TACD, BAYT, TAGT and BAOT. The local Tall Baybay is recommended as planting material while promising varieties like TACD, CATD, AROD, MRD, RIT and Baybay are used for seednuts propagation.

In an attempt to try new breeding methods to produce an open-pollinated variety (OPV), the PCA is introducing the Syn Var 001, nicknamed 'GMA Coconut Variety', or technically known as Genetically Multi-ancestored Farmers Coconut Variety, which is considered as the hybrid of hybrids. The base populations are the F_1 hybrids originating from six Tall populations, which were found to possess good general combining ability. GMA is an open or cross-pollinating population of highly heterozygous individual palms. Farmers can use the succeeding seed generation for subsequent planting and this will make the coconut farmers more self-reliant in the production of their own hybrid seednuts.

Recently, two Philippine Dwarf varieties, Galas Green Dwarf (GALD) and Tacunan Green Dwarf (TACD) passed the international standards set by the C&A Products Co., Ltd. of Thailand for young tender coconut. These were found to be better than the famous Thai aromatic varieties Nam Hom (HOM) and Nam Wan (WAN). A recent addition to the PCA genebank is a rare coconut called 'Tutupaen' or 'Tupa', whose shell is so thick that it's almost as thick as its meat. Nuts from the 'Tutupaen' are not consumed due to superstitious belief that once eaten, the shell will become brittle. Debris from the 'Tupa' tree is also buried for the same reason (Calub 2002). 'Tutupaen' nuts are used solely for 'Tupa', a local throw-and-hit game wherein the players involved try to hit the opponent's nut while it is rolling. The first nut to crack or break is declared the loser regardless whether it is the roller's or the hitter's.

Indonesia

The Indonesia Coconut and Other Palmae Research Institute (ICOPRI) was established to lead the country towards coconut industrialization. Survey and collection of coconut genetic resources were done in several parts of the country, including swampy and drought areas. New Dwarf and Tall ecotypes were introduced to increase the genetic variability of the present collection. ICOPRI has so far collected 165 coconut accessions conserved in four of its experimental stations.

All collected germplasm are conserved in several field genebanks, but since this method was found to be quite expensive, especially the field maintenance (Novarianto *et al.* 1994), cryopreservation technology is being considered as a feasible alternative to conserving the country's coconut germplasm. Characterization of germplasm had been done intensively at the Mapanget experimental garden as a component of the coconut improvement programme in Indonesia. The first four best populations namely, Nias Yellow Dwarf (GKN) from Nias Island (North Sumatera), Tenga Tall (DTA) from Tenga Village (north Sulawesi), Palu Tall (DPU) from Bangga Village (Central Sulawesi) and Bali Tall (DBI) from Pulukan Estate (Bali Island) had been chosen.

Most of the coconuts grown in the country are Tall types. Dwarf types are not commonly planted in large areas, although Nias Yellow Dwarf was used as a female parent in a breeding programme and planted in 1856 ha. The coconut hybrid PB 121 from Port Bouet, Côte d'Ivoire has also been introduced in the country sometime in 1975. In 1984, the government released local hybrids KHINA-1 (GKN x Tenga Tall or DTA0, KHINA -2 (GKN x Bali Tall or DBI) and KHINA-3 (GKN x Palu Tall or DPU). Likewise, Tall x Tall hybrids were released, namely KB-1 (32 x 32), KB-2 (32 x 2), KB-3 (32 x 83) and KB-4 (32 x 99).

Indonesia's coconut genetic resources include 'unique coconuts' as these have unusual morphological traits. Kopyor, the soft-endosperm coconut which is comparable to the Makapuno of the Philippines, has long been used in food preparation. Other unique varieties include Takome and Santongbolang Tall (having remarkable number of fruits per bunch, Igoduku Tall (oblong-shaped), Palapi and Dodo Tall (big fruit and nut), Mamuaya Tall (round fruit with very thin, reddish husk), Shinta Red Dwarf (large bole), Kapal and Pini Tall (pink at the base of the fruit) and Suckering Coconut (suckers grow up from the surface near the base of the trunk). These 'unique' coconuts are among the 40 accessions identified during an exploration activity in the Moluccas Islands, East Nusa Tenggara, West Nusa Tenggara and North Sulawesi, areas that have large coconut diversity (Novarianto *et al.* 2000).

Tall coconut palms are the source of young tendernuts, which is gaining popularity in Southeast Asia. This is mainly due to the fact that the bulk of plantations are growing mainly Tall palms for copra making and oil extraction (Rethinam 2002). However, the cultivation of Dwarf varieties is more appropriate for tendernuts since it is easy to harvest the nuts with little damage. The Salak Dwarf and Nias Green Dwarf are the two coconut varieties recommended by Indonesia for tendernut production. Indonesia and Thailand have also initiated collaborative research on coconut palm sugar production to improve the technology for village-level commercial production and to evaluate coconut germplasm for high sap and sugar production.

Vietnam

Coconuts provide the primary source of income to the thousands of farmers, especially those living in the Mekong River Delta in the south and along the coastal areas in the Central region where coconut planting started several years back. Little attention is given to coconut as most of the coconut farmers prefer intensive farming involving other commodities (i.e., fish, shrimps, swine, fruit crops, etc.) (Long 1994). Coconut is widely used for culinary purposes and some of it is converted into copra and oil for industrial use while the rest is exported.

Coconut research activities in Vietnam were officially initiated in 1980 with the establishment of the Institute for Research on Oils and Oil Plants, now known as the Oil Plants Institute of Vietnam (OPI). Coconut germplasm were planted in OPI's Dong Go Station, in Ben Tre Province, and in Trang Bang Station in Tay Ninh Province. The field genebank in Trang Bang Station was closed in 1994 due to budgetary constraints. The collected local exotic and foreign varieties, including four hybrids from the Institut de Recherchés pour les Huiles et Oleagineux (IRHO), adapted well to the ecological condition of the region.

Aside from the four hybrids from IRHO, OPI's earliest hybrids consisted of two indigenous hybrids Eo x TA and Tam Quan x Ta, two hybrids from the Philippines (JVA1 or MYD x Hijo Green Tall and JVA2 or MRD x Hijo Green Tall) and one hybrid from Sri Lanka (CRI65). Introduced varieties, which showed good performance, include CATD, SGD, MYD, WAT, SNRT and Hijo Tall. Soon after, hybrids were produced locally using the available genetic materials PB121, PB141, JVA1, JVA2, Tam Quan x Hijo Tall, MYD x Ta Tall, MYD x Palu Tall, and MYD x Rennel.

Coconut germplasm collecting is a continuous activity of OPI as it aims to collect all possible types of coconut. Wide genetic diversity can be observed in the country. The Tall types consist of *Ta*, *Dau*, *Giay* and *Bi* or Bung varieties while the Dwarf types include *Ea*, *Xiem* and *Tam Quan*. Cultivars with special characters were also classified according to their distinct feature such as Sap (Makapuno), Ngot (sweet) Dua (aromatic) and Soc (stripe). At present, Vietnam utilizes these varieties in promoting marketing as tendernuts for consumption as an alternative way to alleviate the poverty of coconut growers.

In 2001, the Vietnamese Government allotted US$ 800 000 for a 4-year national project on the 'Production and Deployment of High-Yielding Varieties (HYVs)'. Under this project, four crosses (CATD x LAGT), (MRD x BAOT), (MYD x WAT) and (MYD x BAOT) were produced with pollen coming from the Philippines. About 1000 seednuts are expected from these combinations. This complements an earlier trial wherein three demonstration sites of HYVs from MYD x WAT, MYD x BAO and MYD x BAO were established. About 1000 Makapuno and AROD embryos are cultured in the laboratory.

As of 2001, around 230 000 ha of land is under coconut cultivation in Vietnam, with about 700 000 poor farm families relying on coconut for their livelihood (Long 2002). The ADB-funded/COGENT-coordinated project on 'Reducing Poverty in Coconut Growing Communities in Vietnam' has effectively supplemented ongoing hunger eradication and poverty reduction programme by the government. This project is being implemented in three coconut-producing communities: Hung Phong, Xuan Dong and Tam Quan Nam. Three other communities will be implementing the follow up COGENT project funded by IFAD.

Promotional efforts for marketing newer products made from other raw materials from coconut influences the price of coconut in the country (Rethinam 2002). OPI was commissioned by COGENT to conduct a feasibility study on the production and marketing of coconut fibre products from coconut husk, and coconut handicrafts from coconut shell; and to procure coconut fibre processing equipment for pilot testing to other participating countries.

Thailand

Coconut is an important subsistence crop in Thailand. Over 200 000 farm families are directly or partially dependent on the coconut industry for their livelihood. The total area under coconut is about 376 000 ha, which are predominantly planted with local Tall even though high yielding coconut varieties have been released to farmers since 1982.

Coconut research in Thailand started in 1960 with the establishment of the Sawi Horticultural Experiment Station in Amphoe Sawi, Chumphon Province, later renamed Chumphon Horticultural Research Centre (CHRC), Thailand's main coconut research centre. Over 50 coconut accessions are conserved at CHRC, which include local and exotic varieties. The first hybrid experiment was set up in 1975. The hybrids performed very well under local conditions and a coconut seedgarden was established simultaneously to keep pace with the demand for planting materials. The first variety was Sawi Hybrid No 1, a cross between MYD and WAT, otherwise known as MAWA hybrid. The hybrid was released to farmers in 1982. Two more hybrids, Chumphon Hybrid No. 60, a cross between Thai Tall and WAT (THT x WAT) or Maphrao Yai and West African Tall, and Chumphon Hybrid No.2, a cross between Malayan Yellow Dwarf and Maphrao Yai, were recommended in 1987 and 1995, respectively. Chumphon 60 (named to commemorate the Thai King's 60^{th} birthday) has medium to big size fruit. Potential copra yield per fruit is about 260-300 g. Chumphon 2 has a medium-sized fruit, relatively uniform fruit size and is more precocious than Chumphon 60. Copra yield per nut is about 250 g. Most farmers who had planted hybrid varieties preferred Chumphon 2.

Coconut products such as coconut cream and young tendernut have become important export products of Thailand, becoming the largest exporter of coconut cream to the United States, earning for the country over 2 billion baht (about US$ 40 000 000) each year. Young tendernut is another product gaining popularity, the most famous of which is the Thai Aromatic Green Dwarf (Nam Hon) variety, which is known for its unique sweet and aromatic ("pandan") water. Other varieties include the Thung Khled and Pathiu. The quality and shelf life of fresh nuts have been enhanced, ensuring that the nuts remain in good condition up to 45 days after processing.

Other promising coconut products that are gaining market recognition include coconut sugar and inflorescence sap for bottled soft drink. Handicrafts and novelties from coconut shell are also fast-growing industries that provide the main source of income to some farmer groups, especially in the rural areas of Thailand.

China

The Coconut Research Institute of the Chinese Academy of Tropical Sciences (CRICATAS) introduced into China a host of elite varieties from Vietnam, Thailand, Cambodia, the Philippines, Malaysian and Cote d'Ivoire (e.g., West African Tall, Rennel Island Tall), most of which have been planted in the Institute's seedgarden in Hainan Island. They have also conducted R&D studies on fertilizer application, nutrition diagnosis, cultural systems, intercropping, nut processing and coconut milk preservation.

The country's breeding programme is ongoing, mainly based on MYD x LT crosses. In addition, high-yielding varieties like the MAWA, Thai Green Dwarf and MYD x LT have been deployed. Collecting of indigenous and exotic varieties is continuing to enlarge the stock of parental materials for breeding and screening for cold tolerant varieties. To build up its human resources on coconut genetics research, China continues to send technical staff for related training in other COGENT countries.

Malaysia

In Malaysia, coconut ranks the fourth most important crop in terms of area planted, after oil palm, rubber and rice, respectively. In 1981, the total area planted to coconut was 409 348 hectares, but in 1995 it drastically declined to 248 380 hectares, which represent about 5% of the country's total agricultural land area. As in the rest of the countries in the Asia and Pacific region, smallholders, with an average farm size of 2.8ha, dominate coconut production in the country, producing about 93% of the total coconuts in the country. It is estimated that a total of 90 000 farm families are involved in coconut production.

The local demand for the crop is mainly in the form of fresh nuts, coconut oil and processed products such as desiccated coconut and coconut cream. Despite the shrinkage of the area under coconut, the country is still a net exporter of coconut products. In 1995, exports were valued at about RM 165.2 million (US$ 43.5 million), primarily in the form of coconut oil, desiccated coconut, copra and fresh whole nuts. Imports of coconut and related products, on the other hand, amounted to RM 77 million (US$ 20.3 million). However, over the years, the international prices of copra dropped, which resulted in a corresponding decrease in coconut cultivation and production. The competition for land for oil palm planting and infrastructure development also significantly contributed to the reduction of coconut hectarage in the country. All of these factors have, therefore, endangered the coconut genetic resources of the country.

To mitigate this situation, the Malaysian Government, primarily through the Malaysian Agricultural Research and Development Institute (MARDI), collaborated with a number of international coconut R&D organizations, particularly IPGRI/COGENT, to undertake research and development activities aimed at improving the country's coconut genetic resources.

For a comprehensive listing of completed and ongoing projects in the Southeast and East Asia region, see Annex 2.

Recommendations from member countries

1. Mass propagate unique varieties (i.e., tender coconut, sugar coconut) in farmer's fields under a coconut-based farming system which would also serve as demonstration sites for other coconut farmers;
2. The current ADB-funded 'Poverty Reduction in Coconut Growing Communities' project of COGENT should be replicated in more communities in more countries;
3. The global Coconut Research for Development Programme (PROCORD) should be fully implemented after the dissolution of BUROTROP and subsequent replacement by CIRAD in this research alliance; and
4. The relationship of coconut diversity to environmental protection and human nutrition should receive priority attention from IPGRI/COGENT.

Common constraints and opportunities of the region in relation to coconut genetic resources

Constraints

1. Insufficient varieties that meet product standards for processing into high-value products, also lack of efficient processing techniques and product diversification;
2. Prevalence of pests and diseases, especially Brontispa (in Vietnam and China) and Cadang-cadang (in the Philippines); and
3. Lack of available funds for conducting research and development,

training of staff and procurement of state of the art facilities, including maintenance of field genebanks.

Opportunities

1. The ADB/IFAD-assisted coconut-based poverty reduction projects of COGENT offer a good venue to pursue all regional activities;
2. Vietnam adopted a programme to improve the farming systems common in the Mekong Delta from rice monoculture to diversified crops with high value and marketable agricultural crops; and
3. China is aiming to produce coconut milk juice to meet the huge demand in the country and the international market.

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Annex 1. Member countries of the COGENT SEEA Network, lead agencies and country coordinators

Country	Lead Agencies	Coordinators
China	• Wenchang Coconut Research Institute China Academy of Tropical Agricultural Science	Prof Ma Zitong Prof Tang Longxiang
Indonesia	• Indonesian Coconut and Other Palmae Research Institute	Dr H Novarianto
Malaysia	• Stesen MARDI Kemaman	Mr Abdullah Othman
Myanmar	• Department of Agricultural Planning, Ministry of Agriculture	Mr U Tin Htut Oo
Philippines	• Philippine Coconut Authority	Mr CB Carpio Mr G Santos
Thailand	• Horticulture Research Institute Department of Agriculture • Chumpon Horticultural Research Centre	Mr P Anupunt Mr C Petchpiroon Ms Peyanoot Naka
Vietnam	• Oil Plant Institute of Vietnam	Mr Vo Van Long

Annex 2. List of completed and ongoing coconut projects in the Southeast and East Asian region by country

Country	Project Title
China	a) Collecting, conservation and evaluation of cold-tolerant coconut germplasm in Hainan, Yunnan and Guangdong Provinces b) Development of coconut-based intercropping system to enhance germplasm conservation and incomes of coconut farmers c) Study on the deployment of coconut diversity d) Establishing a framework and selecting project sites for nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in China
Indonesia	a) Collecting, conservation and characterization of coconut genetic resources in Moluccas and Nusa Tenggara Provinces of Indonesia b) Exploration and collecting coconut germplasm from Moluccas East Timor and West Nusa Tenggara c) Strengthening the biotechnology and embryo culture capability of International Coconut Genebank in Southeast Asia host country (Indonesia for Southeast Asia) d) Improvement of in vitro techniques for collecting and exchange of coconut germplasm e) Evaluation of coconut varieties for sap yield sugar production f) Assessment of performance of coconut hybrids and farmers' varietal preferences g) Feasibility study on the establishment of small-scale coconut husk and sugar producing units h) Study on the deployment of coconut diversity i) Catalogue of conserved coconut germplasm j) Importation and growing of designated germplasm from COGENT member countries for conservation in the International Coconut Genebank for Southeast and East Asia (ICG-SEA) k) Coconut embryo culture research to develop effective technology for the production of coconut seedlings from the high quality value soft endosperm 'Kopyor' l) Introduction of coconut germplasm from COGENT member countries into the International Coconut Genebank for Southeast and East Asia m) Establishing a framework and selecting project sites for nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Indonesia
Malaysia	a) Coconut varieties for young nuts (fresh consumption) b) Development of varieties and production technologies for young tender coconuts c) Establishment of a Regional Germplasm Centre for young coconut d) Assessment of performance of coconut hybrids and farmers varietal preferences e) Establishing a framework and selecting project sites for nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Malaysia
Philippines	a) Collecting, evaluation and conservation of coconut genetic resources in the Philippines using a systematic sampling strategy b) Application of standard protocols on coconut genomic DNA isolation, embryo culture and microsatellite SSR molecular markers to support genetic diversity studies and germplasm conservation programs in the Philippines c) Testing of coconut-based farming system (CBFS) to promote conservation in 3 strategic sites d) Refinement of coconut embryo culture technology e) Assessment of performance of coconut hybrids and farmers varietal preferences f) Study on the development of coconut diversity g) Testing the upgraded embryo culture technology to reduce cost of producing embryo-derived makapuno coconut and deployment of resulting seedlings to resource-poor coconut farmers h) Feasibility study on the village scale production and marketing of high vale products (coconut flour and white oil) from fresh coconut meat and identification of suitable varieties for these uses i) Catalogue of conserved coconut germplasm j) Establishing a framework and selecting project sites for nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in the Philippines k) Coconut embryo culture research to develop effective technology for the production of coconut seedlings from high value soft-endosperm coconut variety "Lono" l) Mass production of Dwarf x Makapuno F_1 hybrids and establishing of Regional Makapuno seed farms

Country	Project Title
	m) Improvement of coconut embryo culture technology to promote germplasm collecting, conservation and exchange n) Utilization of embryo culture technology for germplasm conservation: Development of medium term conservation of coconut zygotic embryos o) Feasibility studies on the establishment of integrated coconut husk processing and prototype makapuno production and processing projects in the province of Albay and identification of coconut varieties suitable for the identified high value products
Thailand	a) Coconut germplasm collecting and establishment in field genebank in Thailand b) Varietal improvement for sap yield c) Screening varieties for sugar production and improvement of the quality of granulated sugar d) Assessment of performance of coconut hybrids and farmers varietal preferences e) Feasibility studies on coconut palm sugar and coconut shell handicrafts production f) Catalogue of conserved coconut germplasm g) Establishing a framework and selecting project sites for nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Thailand
Vietnam	a) Coconut germplasm collecting and strengthening of the coconut genebank in Thailand b) Extension of coconut germplasm collection and conservation activities for effective utilization c) Village-level processing of coconut products and survey of varietal preferences d) Assessment of performance of coconut hybrids and farmers varietal preferences e) Feasibility study of Vietnam and purchase and shipment of equipment f) Catalogue of conserved coconut germplasm g) Establishing a framework and selecting project sites for nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Vietnam

Research on coconut genetic resources in Africa and the Indian Ocean

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History of coconut in Africa

The coconut (*Cocos nucifera* L.), which is believed to have originated from the South West Pacific region (Purseglove 1972; Child 1974), has a long history in the African continent. Harries (1990) suggested that the ancestral coconut may have originated from the Western Gondwanaland before it broke-up into the present continents. He argued that during the break-up, coconuts floated to islands in the Pacific and Indian Oceans, even as far as the east coast of Africa (but not into the Atlantic). The fact that the two closest botanical relatives to the coconut, namely *Jubaeopsis caffra* (Uhl and Dransfield 1987) and *Voanioala gerardii* (Dransfield 1989) have been found in Southern Africa and Madagascar, respectively raises the possibility that the wild type coconut might have existed on the fringes of the Pacific and Indian Oceans since the earliest time (Schuiling 1991). In that case, the coconut palm could be considered indigenous to the coastal islands of East Africa.

In addition, Purseglove (1972) postulated that the Malaysian sea rovers introduced the coconut to Madagascar in 1 AD, from where it could have reached the coast of East Africa. Alternatively, it might have been introduced even earlier by Arab traders because there was an interchange of crops between East Africa and India at least 3000 years ago. On the other hand, the early presence of coconuts on uninhabited islands of Seychelles and Mauritius strongly suggests that the first coconuts reached East Africa by floating and drifting (i.e., through natural dispersal).

While the earliest history of the coconut in East Africa remains uncertain (Schuiling 1991), it has been well documented that coconuts did not reach West Africa until after 1499. According to Harries (1977), Vasco da Gama, on his return from India in 1499, took coconuts from East Africa to the west coast of the continent, with Cape Verde as the most probable point of introduction.

The theory that the coconuts in East Africa originated from India is supported by the fact that the common Tall varieties in East Africa are late germinating, wild types similar to the coconuts on the Indian subcontinent (Harries 1978, 1981). This theory is also supported by recent results from molecular studies that show close genetic affinity of some coconut varieties (Laccadive micro and Laccadive ordinary) from India with the local coconut populations in East and West Africa (Rohde 1995; Kullaya *et al*. 2002).

The coconut genetic diversity in Africa is reckoned to be narrow compared to the Asian and Pacific regions. The most predominant Talls found in Africa are the 'Niu kafa type', which according to Harries (1971) have angular, thick-husked and slow germinating nuts. However, old Tall coconut palms with round, thin-husked and early germinating nuts have also been identified in Comoro. There are also yellow, red, brown and green fruited Dwarf varieties which have been introduced into the region at different times for a number of purposes. Furthermore, a number of ecotypes that exhibit considerable differences in palm morphology, fruit colour, size and shape have emerged as a result of introgression between the different populations and adaptation, both of which are constantly taking place.

Unfortunately, there have not been serious and consolidated efforts in most African coconut producing countries to undertake systematic exploration, collecting, conservation and characterization of the available coconut genetic resources. This variability is currently reckoned to be under threat of genetic erosion due to pest and disease incidences, storms, drought, rising sea water, indiscriminate felling of palms due to urbanization and infrastructure development.

Economic importance

The coconut is an important source of vegetable oil and income for many communities in about 22 African countries. It also plays an important role in environmental sustainability of the farming systems of the often fragile ecosystems of the tropical coastal belt.

Africa accounts for only about 5% of the global area and production of coconuts (Persley 1992). According to statistics from Asian and Pacific Coconut Community (APCC 1990), the area under coconuts in Africa is estimated to be about 396 000 ha (Persley 1992). However, data compiled during the First and Second African Coconut Workshops organized by the Bureau for the Development of Research on Tropical Perennial Oil Crops (BUROTROP) in 1991 and 2000 suggest that the area under coconut cultivation in Africa could be about 774 000 ha (Table 1). The largest coconut producers in Africa include Tanzania, Madagascar, Mozambique, Ghana, Côte d'Ivoire and Kenya. The crop is cultivated under diverse climatic and edaphic conditions mainly by small-scale farmers, accounting for about 95% of the total production.

Table 1. Area under coconut in different African countries

Country	Area ('000 ha)	Country	Area ('000 ha)
Benin	10	Madagascar	82
Cameroon	4	Mauritius	3
Cape Verde	3	Mozambique	95
Comoro	30	Nigeria	10
Côte d'Ivoire	50	Sao Tome Principe	37
Guinea	10	Senegal	5
Ghana	43	Seychelles	19
Guinea	15	Sierra Leone	3
Guinea Bissau	25	Somalia	15
Kenya	42	Tanzania	252
Liberia	7	Togo	14
Total for Africa		**774**	

The average coconut yield in the region is quite low (about 600 kg copra/ ha) but comparable to the world's average. According to the findings of two workshops organized by BUROTROP in 1991 and 2000 (Kullaya 1992; BUROTROP 2000), the major and most common production constraints that account for the low coconut yields and productivity in Africa include:

1. Presence of unfavourable weather conditions, in particular inadequate rainfall coupled with unfavourable distribution in a number of producing countries like Benin, Cape Verde, Kenya and Tanzania;
2. Lack of improved planting materials that are adapted to local conditions. The predominant planting materials in the different countries are the local Tall coconut populations, which somehow might be adapted to prevailing local conditions, but generally they have low yield potential;
3. Incidence of serious pests in some countries, in particular:
    - *Oryctes* beetle-The pest occurs in most African coconut growing countries. Although efforts to control another species, *O. rhinoceros* with *Baculovirus* have been successful in various parts of the world, results of such biological control measures under field conditions in countries like Tanzania and Seychelles have been less successful;
    - Coreid bug (*Pseudotheraptus wayi)* in East Africa appears to be far more destructive than the West African species, *P. devastans*;
    - Eriophyid mite (*Aceria guerreronis)*;
    - Rodents, especially in Comoro and Seychelles where two species are reported to occur; and

   - *Melitomma insulare*, which is regarded as the most serious pest in Seychelles.
4. Incidence of the following serious diseases, some of which are lethal:
   - Lethal Yellowing-type diseases (LYD) caused by phytoplasmas, which are widespread over most of the coconut growing regions on the west and eastern coasts, and they considered to be the most important threat to coconut production in Africa (Eden-Green 1995). These diseases are known by different names in different countries. In West Africa, LYD occurs in Ghana (known as Cape St Paul disease or CSPWD), Togo (Kaincopé disease), Nigeria (Awka wilt), and Cameroon (Kribi disease). Similarly, on the East coast, the disease occurs in Tanzania (lethal disease), Kenya and Mozambique.
   - *Phytophthora katsurae* that causes nutfall and spear rot in West Africa, particularly in Côte d'Ivoire.
5. Poor extension and technical services to farmers, largely caused by:
   - Inadequately trained extension workers, particularly those based in the villages;
   - Lack of appropriate technology packages for dissemination; and
   - Inadequate support from the government to extension staff (low salaries, poor housing and transport facilities, etc).
6. Poor crop husbandry practices. Coconut farmers are either reluctant or can not afford to apply improved crop husbandry practices, fertilizers, chemicals, etc; and
7. Lack of rehabilitation programmes to replace old and senile palms.

Coconut research and development programmes

National coconut research and development programmes

Only a few countries such as Benin, Côte d'Ivoire, Ghana, Nigeria and Tanzania have long-term R&D programmes and strategies to promote the coconut sector. Coconut research stations in Benin and Côte d'Ivoire were established about 50 years ago, which are the oldest in the region. The general objective of these national coconut R&D programmes is to promote the production and utilization of coconuts by addressing the most important constraints. Current activities, which differ in scope from country to country, include:

- Germplasm conservation, characterization and utilization;
- Breeding for high yield with improved precocity and adaptability

to local conditions. In this regard, Côte d'Ivoire has played an important role in coconut breeding, for example, a number of hybrids bred in Côte d'Ivoire have been planted in more than 40 countries worldwide;
- Agronomic trials, including, spacing, intercropping and fertilizer trials with a view to develop improved coconut-based farming systems;
- Studies on the aetiology, epidemiology and control of important diseases such as *Phytophthora* in Côte d'Ivoire and LYD in Ghana, Tanzania and Nigeria;
- Development of effective pest control strategies against major pests, in particular the coreid bug (*Pseudotheraptus* spp.);
- Production and distribution of improved planting materials to farmers for rehabilitation programmes; and
- Development and dissemination of improved small-scale coconut processing technologies.

In the 1980s, some initiatives to rehabilitate the coconut industry were taken in Comoro, Seychelles, Mozambique, Cape Verde and in other countries by introducing high-yielding coconut hybrids, mainly PB 121 from Côte d'Ivoire. However, these efforts were not sustained after the respective projects came to an end.

Meanwhile, plans are at an advanced stage in Ghana and Mozambique to initiate coconut rehabilitation programmes with financial support from France. The main components of the project to be conducted in Mozambique include: development of control methods of LYD, training of local staff and farmers, improvement of crop husbandry practices and promotion of small-scale oil processing.

Regional coconut genetic resources activities

Prior to the involvement of BUROTROP and the International Coconut Genetic Resources Network (COGENT), there were hardly any regional coconut activities in Africa. Most activities were either confined to individual countries or carried out on a bilateral basis, mainly in the area of supply of genetic material for research or replanting purposes. With the establishment of the two international bodies, there has been significant progress with respect to regional collaboration and networking. Table 2 gives the list of collaborative projects that have been initiated through one or both organizations.

Table 2. List of regional projects initiated through BUROTROP and/or COGENT

Project	Institutions and Countries Involved	*Status*
Investigation in the aetiology and control of lethal yellowing-type diseases	- Mikocheni Agricultural Research Institute (MARI) (Tanzania) - Ministry of Agriculture (Ghana) - Marc Delorme Station/CNRA, Côte d'Ivoire - Natural Resources Institute (NRI) – UK - CIRAD – France	Completed
Promoting small-scale coconut oil processing techniques	- MARI (Tanzania) - Ministry of Agriculture (Ghana) - Marc Delorme Station/CNRA, Côte d'Ivoire - NRI (UK) - Indonesia	Completed
Development of improved coconut-based farming systems	- MARI (Tanzania) - Philippine Coconut Authority - NRI (UK) - CIRAD (France) - Vanuatu	Completed
Improvement of coconut by biotechnology: Application of DNA marker technology to germplasm characterization and breeding	- MARI (Tanzania) - Philippine Coconut Authority - Max-Planck-Institute for Plant Breeding (MPIZ) from Germany and - NEIKER from Spain	Completed
Construction and exploitation of high-density DNA marker and physical maps in the perennial tropical oil crops coconut and oil palm: from biotechnology towards marker-assisted breeding (LINK2PALM)	- MPIZ (Germany) - NEIKER (Spain) - CIRAD (France) - Philippine Coconut Authority - Malaysia Palm Oil Board (MPOB) - Indonesia Oil Palm Research Institute (IOPRI) - SOCFINDO (Indonesia) - Marc Delorme Station/CNRA, Côte d'Ivoire - CICY (Mexico) –as sub-contractor - MARI (Tanzania) - as sub-contractor	Ongoing
International Multilocation Variety Trial	- National Institute for Agricultural Research (INRAB), Benin - Marc Delorme Station/CNRA, Côte d'Ivoire - MARI (Tanzania) - EMPRESA Brasileira de Pesquisa, Agropecuaria (EMBRAPA) Brazil) - Coconut Industry Board, Kingston, Jamaica; - Instituto Nacional de Investigacion Forestales Agricoles y Pecuario (INIFAP), Mexico	Ongoing
Establishing a framework and selecting project sites for a nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's three-pronged strategy	- 18 countries, including Tanzania and Ghana	Completed

In 1996, the Coconut Genetic Resources Network for Africa and Indian Ocean (CGRN-AIO) was formally established to promote collecting, conservation, characterization, evaluation, use and exchange of coconut genetic resources in the region, as sub regional network of COGENT. It also aims to accelerate the development and use of improved coconut varieties and hybrids. Kenya, Madagascar, Mozambique, Seychelles and Tanzania in East Africa, and Benin, Côte d'Ivoire, Ghana and Nigeria in West Africa are the current members of the regional network.

Status of the International Coconut Genebank site for Africa and Indian Ocean (ICG-AIO)

The Marc Delorme Station of the National Centre of Agronomic Research (CNRA) of Côte d'Ivoire has been designated as the site for the International Coconut Genebank for Africa and Indian Ocean (ICG-AIO) countries. The ICG is about 200 ha and is situated about 15 km from the ocean. It receives about 1600 to 1900 mm of rain, which falls in two seasons. The soils are homogenous with a light texture (less than 40% clay) which can allow the roots of coconut to penetrate beyond the depth of four meters. The station hosts a collection of 53 coconut populations from different parts of the world, out of which 49 accessions (Table 3) have been included in the ICG-AIO. The memorandum of agreement formalizing the establishment of the ICG-AIO was signed by the Government of Côte d'Ivoire with IPGRI/COGENT in 1999. CNRA/Marc Delorme Station uses its own resources to maintain, characterize, evaluate and rejuvenate some of the populations that are becoming too tall.

The ICG, which has excellent infrastructure (greenhouses, field genebank and laboratories), will be a centre of excellence for training scientists from the region on coconut germplasm conservation, characterization, evaluation and utilization. Emphasis in training will be put on breeding techniques, embryo culture, methods for germplasm prospecting and in molecular technologies for diversity assessment. In addition to the 49 cultivars, the ICG-AIO intends to introduce different germplasm from other countries in Africa and from the other regional ICGs of COGENT.

Future activities

Taking into consideration the relatively high annual population growth rate in Africa, the demand for vegetable oil is expected to increase progressively in the coming decades. Appropriate actions must therefore be taken to enable countries in Africa and the Indian Ocean meet this increasing demand for vegetable oil.

During the Second International Coconut Workshop for Africa titled, 'Helping the African Coconut Farmer into the 21st Century' organized

Table 3. List of germplasm accessions covered by the agreement for the ICG–AIO

	International Cultivar Name	Abbreviation (Code)	Source (Country of Origin)
1.	Andaman Giant Tall	AGT	India
2.	Andaman Ordinary Tall	ADOT	India
3.	Baybay Tall	BAYT	Philippines
4.	Cambodia Battambang Tall	KAT09	Cambodia
5.	Cambodia Koh Rong Tall	KATIO	Cambodia
6.	Cambodia Ream Tall	KAT07	Cambodia
7.	Cambodia Sre Cham Tall	KAT08	Cambodia
8.	Cambodia Tuk Sap Tall	KAT02	Cameroon
9.	Cameroon Kribi Tall	CKT	Cameroon
10.	Cameroon Red Dwarf	CRD	Cameroon
11.	Catigan Green Dwarf	CATD	Philippines
12.	Comoro Moheli Tall	CMT	Comoro
13.	Equatorial Guinea Green Dwarf	EGD	Equatorial Guinea
14.	Gazelle Peninsula Tall	GPT	Papua New Guinea
15.	Kappadam Tall	KPDT	India
16.	Karkar Tall	KKT	Papua New Guinea
17.	Kinabalan Green Dwarf	KIND	Philippines
18.	Laccadive Micro Tall	LMT	India
19.	Laccadive Ordinary Tall	LCT	India
20.	Madang Brown Dwarf	MBD	Papua New Guinea
21.	Malayan Green Dwarf	MGD	Malaysia
22.	Malayan Red Dwarf	MRD	Malaysia
23.	Malayan Tall	MLT	Malaysia
24.	Malayan Yellow Dwarf	MYD	Malaysia
25.	Markham Valley Tall	MVT	Papua New Guinea
26.	Mozambique Tall	MZT	Mozambique
27.	Niu Leka Dwarf	NLAD	Fiji
28.	Palu Tall	PUT	Indonesia
29.	Pilipog Green Dwarf	PILD	Philippines
30.	Rangiroa Tall	RGT	French Polynesia
31.	Rennell Island Tall	RIT	Solomon Island
32.	Rotuman Tall	RTMT	Fiji
33.	Solomon Island Tall	SIT	Solomon Island
34.	Sri Lanka Green Dwarf	PGD	Sri Lanka
35.	Sri Lanka Tall Ambakelle	SLT02	Sri Lanka
36.	Tacunan Green Dwarf	TACD	Philippines
37.	Tagnanan Tall	TAGT	Philippines
38.	Tahitian Red Dwarf	TRD	French Polynesia
39.	Tahitian Tall	TAT	French Polynesia
40.	Takome Tall	TKT	Indonesia
41.	Tonga Tall	TGT	Indonesia
42.	Ternate Brown Dwarf	TBD	Indonesia
43.	Thailand Green Dwarf	THD	Thailand
44.	Thailand Tall Ko Samui	THT04	Thailand
45.	Thailand Tall Sawi	THTO I	Thailand
46.	Tonga Tall	TONT	Tonga
47.	West African Tall Akabo	WAT03	Côte d'Ivoire
48.	West African Tall Mensah	WAT04	Côte d'Ivoire
49.	West African Tall Ouidah	WAT06	Benin

by BUROTROP in collaboration with the Coastal Development Authority of Kenya from 8-12 May 2000 in Mombassa, the participants from Kenya, Madagascar, Mozambique, Tanzania, Nigeria, Ghana, Côte d'Ivoire and Benin recommended that African coconut producing countries should collaborate with regional and international organizations in order to revive the coconut industry (BUROTROP 2000). More specifically the participants agreed to:

1. **Promote the collecting, conservation and exchange of germplasm**. Generally, there is inadequate information on the

extent and location of coconut genetic diversity in Africa. It is therefore necessary to develop strategies for promoting coconut genetic resources activities at both national and regional level. There is a need to organize joint exploration and collecting missions especially in the Eastern African countries and the adjacent islands because of the much longer history of coconuts in this sub-region as compared to West Africa. The genetic materials that will be collected will have to be conserved in the national genebanks as well as in the ICG-AIO. Efforts should also be made to characterize and evaluate the germplasm in the national genebanks and in the ICG-AIO, and to use the genetic materials in national breeding programmes to address priority objectives such as improved yield, resistance to LYD, drought tolerance and early bearing. In pursuing the national breeding programmes due emphasis should be given to the local germplasm. However, introduction of genetic materials from other countries within and outside the region will be inevitable because of the limited genetic variability that exists in most countries in the region;

2. **Promote national coconut germplasm conservation** through coconut-based farming systems and/or the use of high-value added products. The conservation of coconut germplasm in field genebanks is an expensive activity that cannot be achieved by all countries in the region. It is therefore necessary to develop novel strategies that will:
    - Encourage *in situ* conservation;
    - Improve productivity of the farming systems through intercropping and integration of livestock; and
    - Promote value-adding activities through small-scale processing of different coconut products;
3. **Utilize the international and national coconut germplasm collections** in screening for resistance to lethal yellowing-like diseases, drought tolerance and other constraints. In view of the fact that biotic and abiotic stresses continue to take a heavy toll on coconut production in the region, regional efforts and international collaboration are necessary in screening for resistance against the different biotic and abiotic stresses; and
4. **Foster technology transfer and strengthen research capacity** of national programmes on coconut germplasm conservation and utilization. Many national programmes lack adequate human and infrastructure resources. The Marc Delorme Station/CNRA in collaboration with research programmes in other countries would organize training workshops and courses for researchers

and technicians from the other coconut producing countries. Emphasis will be on standardized coconut breeding techniques, embryo culture, methods for germplasm prospecting and in molecular technologies for diversity assessment.

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Research on coconut genetic resources in Latin America and the Caribbean

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Introduction

The coconut (*Cocos nucifera* L.) is a very important crop in Latin America and the Caribbean (LAC) for both cash and subsistence. It is not indigenous to the Americas; it was introduced from the old world. The first introductions originated from Cape Verde (West Africa) to the Spaniola Island (now Haiti and Dominican Republic) in the Caribbean (Bruman 1944; Harries 1977). Introductions to the west coast occurred from the Solomon Islands around 1569 and from the Philippines to Mexico in various occasions between 1571 and 1821 (Smith 1970; Zizumbo *et al*. 1993). Coconut was present in Panama from pre-Columbian times but its origin and introduction date is unknown (Zizumbo and Quero 1998). It was brought to the Americas for the establishment of plantations and the fruit was used primarily for the production of wine and secondarily for fresh consumption. Wine production from coconut was forbidden and hence, from the second half of the 17th century to the second decade of the 20th century the use of the fruit for fresh consumption became the primary use. Then, during the 1920's, copra became the main product from coconut (Zizumbo *et al*. 1993). Nowadays, the trend is towards product diversification.

Coconut is cultivated in every continental land from Brazil to Mexico and in the Caribbean islands. Currently it is grown on about 500 000 ha, or about one-twentieth of the coconut area in the Asia Pacific. The main producers are Brazil (over 200 000 ha) and México (about 160 000 ha) in the continent and Jamaica (14 000 ha) in the Caribbean. It is also abundant in the Florida State in the USA, but for ornamental purposes.

Unfortunately, there are many problems with coconut cultivation and industry, and most of them are common in every LAC country: (a) use of low-yielding varieties; (b) ageing of palms; (c) losses due to diseases and pests; (d) adverse climatic conditions; (e) inadequate management practices; (f) stagnation and/or declining prices of products; (g) under utilization of the crop and limited diversity of products; and (h) unstable markets.

The problems (a) to (c) are directly related to the features of the presently cultivated palms, hence there is a lot of interest in research related to germplasm and in particular the identification of genotypes resistant to the phytoplasma-associated disease lethal yellowing (LY). The LY is currently the most worrying problem of the coconut cultivators. Problems (f), (g) and (h) are particularly related to copra production and can be approached by promoting utilization of by-products and product diversification. Problem (d) is generally beyond human control. However, in the case of hurricanes that unfortunately occur every year, in the Caribbean region in particular, the use of coconuts that can resist strong winds can be very useful. Then again, this is a germplasm-related approach. In the case of problem (e), it is very likely that neglect of plantations may result from the effect of the other problems; therefore, if they are properly solved, farmers would be interested in investing in their plantations.

Genetic resources research and achievements

As mentioned above, the disease LY is a major concern among the coconut farmers, and of the coconut industry as a whole. Hence, in most producing countries in LAC there is a lot of interest on LY research. Currently, the principal management tool against LY is the use of resistant germplasm (Been 1995a). The present section focuses on those aspects of research related to coconut genetic resources in the LAC region, including the search for LY resistant genotypes. A wider review on research on LY is presented in Chapter 6.

Search for suitable lethal yellowing resistant coconut germplasm

Trials evaluating coconut genetic resources for LY resistance, have been performed in Jamaica by the Coconut Industry Board (CIB) since the 1960s (Been 1981). When LY appeared in the main coconut growing region of the island in 1961, selection and breeding focused on disease resistance. Local varieties were identified, characterized and tested. At the same time, exotic materials were introduced and tested. Resistance was found in some of these materials, including the Malayan Dwarf (MD) varieties. Seeds of these varieties were released to farmers for replanting. The Malayan Yellow Dwarf (MYD) variety was subsequently used as a parent for F_1 hybrid production because of its good resistance although it has certain undesirable agronomic characteristics. Hybrids produced with MYD as one of the parents had a level of resistance sufficient to be used for commercial planting. In 1971, it became clear that two-parent hybrid seed gardens were inadequate for large-scale seed production.

Before mass controlled pollination could be introduced, research had to be done on how to produce large quantities of viable pollen. This having being completed, work was done on emasculation and pollination techniques to obtain maximum seed set. Routine procedures were established including the use of a mobile pollen workshop (Been 1995b). In 1974, the MayPan, a cross between the MYD and the Panama Tall, was released to the farmers. It possessed the hardiness of the Panama Tall and LY resistance of the MYD. In 1974, a 52-hectare hybrid seed farm was established in an isolated area, using the MYD as mother palm. The breeding programme has continued. Palms of cultivars other than MYD which have survived LY were sib-pollinated and F_1 hybrids of such crosses were field tested. It is now possible to test for the presence of phytoplasmas by using PCR analysis.

In Mexico, LY appeared in 1977 (McCoy *et al.* 1982) and immediately after, following Jamaica's findings, the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP) started the production of hybrids using MYD that had been introduced to the country a few years before and the Pacific Tall (PT) coconuts that were introduced during the 16th to 19th centuries. These hybrids survived LY and some of them proved to be very high yielders (INIFAP 2005, unpublished).

A few years later, in order to increase the genetic base of LY resistant coconuts, a search for LY resistant germplasm began in Mexico. Centro de Investigación Científica de Yucatán (CICY) collected 18 coconut populations mostly from the Pacific coastal areas of Mexico in 1989, where LY was not present. With these populations, resistance trials were established in Yucatan in an LY affected area. These populations were grouped into three ecotypes: Pacific Tall 1 (PT1), Pacific Tall 2 (PT2), and Pacific Tall 3 (PT3). After more than ten years of testing, new LY highly resistant germplasm have been identified, namely PT 1 and PT 2 (Zizumbo *et al*. 1999). They are also surviving in their original planting locations (CICY 2005, unpublished) where they co-exist with different LY phytoplasma strains (Harrison *et al*. 2002). These varieties were also evaluated for other traits including: germination rate, growth rate, early bearing, productivity, adaptation to prevailing local conditions and hurricane tolerance; and good performing individual palms were identified. They are currently being used for improvement and replanting programmes in Mexico and Honduras. Testing of these ecotypes and their Tall x Tall progenies started in Jamaica three years ago to determine if they could survive the resurgence of LY outbreaks in the country.

In addition, testing of MYD x PT hybrids started in Mexico in 2000 within a project coordinated by the International Coconut Genetic Resources Network (COGENT). In this multi-country project, Empresa

Brasileira de Pesquisa Agropecuária (EMBRAPA, Brazil), CIB (Jamaica), and INIFAP and CICY (Mexico) are partners representing LAC. The objectives are: to assist each of the six countries involved in the project to identify suitable high-yielding varieties/hybrids with high adaptation to prevailing local conditions; and to estimate genotype x environment interaction. Each country is testing six common hybrids (produced by Centre National de Recherche Agronomique or CNRA in Cote d'Ivoire), and additional materials, mostly hybrids of particular interest for each country. Evaluation includes traits of agronomical interest such as yield and adaptation to prevailing local conditions and survival to lethal diseases, where applicable. The results will be very useful for each country involved, but they could also serve as a guide applicable to other countries with similar cultivation conditions.

The results obtained from the research in Jamaica and Mexico have been very useful for farmers. In Jamaica, seeds of the MYD during the 1960s and of the MayPan hybrid during the 1970s were released to farmers for extensive replanting programmes that continue even today. These programmes of extensive replanting with the highly LY resistant MYD and MayPan have been the basis of survival of the coconut industry in Jamaica. In Mexico, the identification of LY resistant germplasm and the production of Dwarf x Tall hybrids initiated replanting programmes that have become stronger with the involvement of a national farmers organization within the past two years. Both LY resistant materials from Jamaica and Mexico, and the hybrid production technology from Jamaica have also strengthened the national programmes for dealing with LY in other countries in Central America and the Caribbean.

Unfortunately, unusual high losses of resistant MYD and MayPan hybrid coconuts have been reported in Florida and Jamaica (Howard *et al*. 1987), and recent outbreaks in northern Jamaica have killed up to two thirds of MYD and MayPans (Harrison *et al*. 2002a). Therefore, a future search for additional sources of resistance is top priority. Fortunately, coconut genetic diversity is common occurrence in most LAC countries. However, a precise identification or confirmation of the identity of each genotype or population is needed in most cases (see *Germplasm characterization* below).

Other diseases and pests

As reported by Dollet (1999), the other serious threats in LAC are: hartrot, a trypanosome disease that has been observed in all the countries from Brazil to Honduras, including Trinidad (where it is known as Cedros wilt) and Costa Rica; *Phytophthora* bud rot, a disease that has reached epidemic proportions not only in LAC but worldwide; and red ring caused by the *Rhadinaphelencus cocophilus* nematode that is transmitted by the palm weevil *Rhynchophorus palmarum*.

Another lethal disease of great concern is porroca or little leaf disease, formerly restricted to areas around Cartagena, Colombia and the Panama-Colombia border but recently entered an epidemic phase, spreading along the Caribbean coast and inland to 40 km west of the Panama Canal (Gilbert and Parker 2001). Dollet (1999) also pointed out the occurrence of other diseases and various pests that similarly hinder coconut palm development in the region: *Castnia dedalus* Cramer larvae that mine galleries in the stem, *Strategus aloeus* L. that can kill young palms during the first dry season of their planting, and the fungal diseases Lixa and Queima das Folhas (particularly important in Brazil).

However, for *Phytophthora* spp. (Meerow 1997), *R. palmarum* (Chinchilla *et al*. 1996), *S. aloeus* (Bustamante 2002) and trypanosomes (Magán *et al*. 2004), chemical control (sometimes using mechanical devices) is available. It is worth mentioning that research on some of these diseases is carried out within LAC. In the case of porroca, collaborative research has been carried out by the University of California, Santa Cruz and the University of Florida in the United States studying the case in Panama. In addition, potential cytotoxicity of the three new triazolo-pyrimidine derivatives against plant trypanosomes has been found in a study reported by the researchers from Universidad de Granada in Spain and Universidad Autónoma de Yucatán in México (Magán *et al*. 2004). In the case of *R. palmarum*, a control system based on the use of pheromones and a mechanical trap was developed by Chinchilla *et al*. (1996) in Costa Rica and it is since extensively used.

Hurricane tolerance

Jamaica is in the hurricane zone and over the years, hurricanes have had a significant effect on the industry. The MayPan is more resistant to windstorm than the Malayan Dwarf and starting with late generation Fiji-Malayan cultivars, some progress is being made in producing a palm possessing a thick trunk, early bearing, good yield stability and LY resistance in tandem with good windstorm tolerance. In 2002, in the Yucatan coast in Mexico, hurricane Isidoro fell large numbers of coconuts. Analyses of data showed significant differences on the percentage of palms of different genotypes that were affected: PT ecotypes 5%, Atlantic Tall (AT) 35%, MYD x AT hybrid 27%, MYD x PT hybrid 34% and MYD over 50% (CICY 2005, unpublished).

Germplasm characterization

In order to obtain the most out of the available germplasm in LAC and other locations, it is very important to characterize them using different techniques. The most powerful tool currently available for this purpose is microsatellite markers. A kit of such markers was developed by Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD, France) jointly with COGENT (Baudouin and Lebrun 2002). Additional techniques such as morphological characterization (Harries 1981) can be of great practical importance. An immediate application of these techniques is to properly define the identity of genotypes of interest for LY resistance screening within the known germplasm diversity, as well as bringing in new genotypes from Asia. Search for uncharacterized populations within the Pacific coasts of Central and South America could also be initiated in a similar fashion as it has been done before in Mexico (Zizumbo *et al*. 1993; 1999; 2002). The initial selection of populations on the LAC Pacific coasts can be supported with morphological characterization technique. Both the characterization of newly discovered Pacific populations and the selection of Asian genotypes can be supported by the use of microsatellites markers to assess the genetic distance to already known and characterized LY resistant genotypes.

In vitro culture techniques

There is another area of research that is complementary to those already presented above: *in vitro* culture of coconut. It is necessary for two main reasons. One is the need of protocols for zygotic embryo culture for the safe movement of coconut germplasm. The participation of Mexico in a COGENT-coordinated project allowed the country to develop such a protocol as reported in Pech and Ake *et al*. (2002) and in its further refinements (Pech and Ake *et al*. 2004). This protocol will be used to bring genotypes of interest from Asia into Mexico as part of a Common Fund for Commodities (CFC)-supported project. The other need for *in vitro* culture is the massive and rapid propagation of genotypes and elite individuals through micropropagation. Again, Mexico has been involved in the development of protocols for such a need based on somatic embryogenesis and the use of plumule explants. In 1998, Chan *et al*. reported for the first time a protocol for coconut micropropagation that was reproducible and quantifiable in terms of yields. However, efficiency was very low, about ten somatic embryos and fewer plantlets could be obtained per plumule explant (Azpeitia *et al*. 2003). Further improvements based on secondary somatic embryogenesis and multiplication of embryogenic callus have allowed obtaining tens of thousands of somatic embryos from a single plumule explant (CICY 2005, unpublished). This protocol still requires refinements but it can be envisaged that within about three to five years, it will be ready for practical applications in coconut producing countries. A more detailed account of coconut *in vitro* culture can be found in Chapter 2.

Plant management

At the time of the LY outbreak in 1961 in Jamaica, research was conducted in improving management for the Jamaica Tall cultivar as well as for new LY resistant cultivars. Research initially concentrated on the use of fertilizer, tillage, methods of managing bearing trees with different incropping patterns and rat control. Great progress was made including the development of a water-proof rat bait which was subsequently used by the local farmers and in some other Caribbean countries (CIB 2005, unpublished). When new varieties were produced, a new range of experiments was needed to determine the best planting methods, most desirable spacing, weed control, fertilizer and intercropping patterns. Pioneering work was done on the use of herbicides in coconut cultivation and routine herbicide recommendations were developed and adopted by farmers in Jamaica and elsewhere (CIB 2005, unpublished). In addition, technology has been developed on biofertilizer application for Atlantic Talls in Mexico. The advantages of using biofertilizer are its low cost and ease of application.

Other aspects of relevance

Utilization and marketing

These areas are of vital importance for the coconut industry in any country. In LAC, the stronger countries in these areas are Brazil, Jamaica and Mexico but the development and marketing of diversified coconut products in these countries have yet to be fully developed; and in the other producing countries of LAC, they are completely neglected. Just a few years ago, it was common to find coconut used only for copra production, but recently because of unstable market for copra and coconut oil, the focus has shifted to the fresh coconut market. However, this is not an action resulting from a well-planned strategy, which is lacking, probably because in most countries of the region the coconut farmers and processors are not organized, perhaps with the exception of Jamaica where there is a coconut industry board and in Mexico where the farmers also have organized themselves (see next section). There is a need for a well-planned strategy for diversification in order to improve income, particularly foreign revenues for non-traditional products and by-products, including improvement of existing and new markets (Punchihewa 1995). Fortunately, this view has been taken in the region initially by Jamaica and by other countries including Brazil and Mexico, and also in countries such as Dominican Republic where interest in coconut is becoming stronger.

Collaboration and networking

Something very important in making progress in coconut cultivation and utilization for the benefit of small-scale farmers and the coconut industry as a whole is to collaborate with concerned local and international agencies, and with other coconut growing countries. Fortunately, the coconut community has COGENT, the Asian and Pacific Coconut Community (APCC) and the Bureau for the Development of Research on Tropical Perennial Oil Crops (BUROTROP) that promotes collaborative efforts as part of their regular activities. COGENT does so in the field of genetic resources and being itself a network, one of its objectives is to promote networking or sub-networking for each of its service geographic areas. As a result of COGENT support and guidance in LAC, collaboration and joint activities among the 10 member countries of the LAC-COGENT Sub-network and those outside it, is occurring and steadily increasing. One aspect that is of particular interest in most countries is dealing with LY, because either they are already affected by the disease or threatened by its arrival. These activities include:

Exchange of germplasm. PT ecotypes and PT x PT hybrids from Mexico were sent to Jamaica and Honduras in 2002, and Brazil Green Dwarf (BGD), Brazil Tall (BT) and the BGD x BT hybrids were sent from Brazil to Jamaica in 2004 for evaluation of resistance to local yellowing diseases.

Technical advice. Information on LY prevention and control has been provided by Jamaica to other countries. Personnel from CIB visited Mexico and countries in the Caribbean to provide technical advice on LY. Guatemala and Honduras, countries affected by LY, requested support from Cuba and Mexico whose consultants visited the requesting countries in 2002-2003 to help establish comprehensive national coconut programmes. Similarly, a consultant from Mexico visited Dominican Republic in 2004 to evaluate the dispersion of LY in this country and help in the preparation of a national coconut programme.

Training. Institutions from Jamaica, Honduras and Mexico provided training in different subjects for dealing with LY to technicians from other countries; and participated in workshops and theoretical and practical courses in different countries already affected by LY within the Caribbean and Central America. For instance, visits to countries in Central America were carried out by CICY staff in 2002 to provide technical advice and training to technicians and scientists. These visits were supported by the United States Department of Agriculture (USDA).

Collaboration and information exchange with countries outside the LAC region. This occurred since the 70's and continues with researchers from the University of Florida (USA), Max Planck Institut für Züchtungsforschung (MPIZ, Germany), Rothamsted Research (UK), CIRAD and L'Institut de Recherche pour le Développement (IRD, France), among other institutions.

Joint research. Collaborative research has been carried out involving institutions mainly from Jamaica, Cuba, Honduras and Mexico together with those mentioned above from outside the LAC region. It has focused on LY and in the next few years, it will become more intensive particularly in response to the new and devastating LY outbreaks in Jamaica for which no effective sources of resistance or control options are currently known. A meeting with the participation of several experts was held in Jamaica in January 2002 in order to implement a concerted effort among several institutions in different countries. A project initiative emerged entitled, 'Sustainable Management of Coconut Lethal Yellowing Disease' with the aim of improving international collaboration and support research on coconut lethal yellowing. It is directed at maintaining and improving coconut production, in particular by smallholders, in a sustainable manner. It intends to benefit coconut farmers in Central America, the Caribbean, Africa and other regions. The project will strengthen international collaboration, in particular in the Caribbean and Central America, among countries affected by coconut lethal yellowing and related diseases. It will provide urgently needed technical assistance to research efforts aimed at identifying disease-resistant coconut germplasm. It will also develop detection methods for the suspected resistance-breaking new pathotype of the disease which are needed for phytosanitary and research purposes. In addition, it will advance knowledge on disease epidemiology, spread/transmission, and on possible control options. Coconut farmers in outbreak areas will participate in efforts to find sources of resistance and cultural control methods. It will be carried by institutions from Jamaica, Mexico, and Honduras; financed by government counterpart contributions and CFC; and supervised by the Food and Agriculture Organization of the United Nations (FAO).

Networking. Most of the activities mentioned above have been carried out within the framework of the LAC COGENT sub-network. Also, during the recent RedBio (Red de Cooperación Técnica en Biotecnología Vegetal para América Latina y el Caribe)/FAO V Latin American and Caribbean Meeting on Agricultural Biotechnology in Dominican Republic in 2004, representatives of different LAC countries formed 'The Latin America and the Caribbean Lethal Yellowing Network' (REDALC) to promote research and development for LY in coconut and discuss a regional LY research programme. REDALC is linked to COGENT and is consistent with COGENT's interest in the formation of a world thematic group. Although this is a LAC network, one of its objectives is linking with countries with similar interests in other continents. In addition, national networks have been formed in Honduras (Red Wafaluma) and Mexico (Red Mexicana de Investigación y Desarrollo del Cocotero) with the participation of representatives of research institutions, government, non-government organizations and farmers. These networks promote different aspects that can help to improve coconut cultivation and utilization although their main current concern is LY.

National farmer organizations. The lack of organized farmer associations is a very significant shortcoming in LAC coconut producing countries, with the exception of Jamaica with its CIB. The CIB is a well-structured organization that was established in 1945 as a statutory corporation by law to administer the coconut industry, under the Ministry for Agriculture. The main objectives of the Board are to organize the orderly disposal of the coconut products to the best advantage of the growers, and to encourage and assist the farmers in all aspects of growing the crop. It operates on the premise that there is an obligation to find a market for the entire produce, and a duty to encourage the growing of coconuts to meet the needs of the country (Been 1995c). In Mexico, a national association of coconut farmers was recently formed. It is called 'Consejo Nacional del Coco'.

The way ahead

As already mentioned a key aspect for a substantial improvement of the coconut cultivation and utilization for the benefit of farmers and the industry as a whole, is collaboration at all levels: among farmers and among all parties involved in the coconut industry that can affect it positively, within and between countries. Therefore, the existence of farmer organizations and national and international networks, and the effective interaction among them, and with international organizations such as COGENT and APCC, are top priorities. Specifically, there is a need to consolidate particular actions on priority researches for coconut. It is a must to characterize the existing coconut germplasm and to widen the coconut genetic base by importing genotypes from other parts of the world and searching for them within LAC, particularly for screening for LY resistance. Attention should also be paid to other phytosanitary threats. Protocols for massive propagation of disease resistant, high-yielding, hurricane tolerant (among other traits) cultivars should be developed and made available for rapid seedling production. It is also very important to improve coconut management, utilization and commercialization. In LAC, work is already in progress on these aspects, but it is very important to ensure that this continues and that any achievement is translated into benefits for the coconut industry as a whole. Moreover, the best way to do it is, through a very strong LAC coconut community that works very closely with the rest of the world coconut community.

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Chapter 9

Country reports on status of coconut genetic resources research

South Asia

Status of coconut genetic resources research in India

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Introduction

India, the world's third largest producer of coconut, grows the crop in four of its southern states: Kerala, Tamil Nadu, Karnataka and Andhra Pradesh.

The crop is grown in wide range of agroclimatic and sociocultural-economic conditions. Land area under coconut, primarily located at latitude 23.83^0 N to 6^0 S and longitude 94.78^0 E to 60^0 E, is characterized by ecosystems of high rainfall zones (Northeast) to regions with wide differences in relative humidity (46% to 99%) and extremes of temperature (4^{0}C to 35^{0}C). The management of the crop varies from monocropping with sophisticated drip irrigation, to mixed gardening in home gardens to wild stands in uninhabited islands. Planting density also vary - from wide spacing of 150 palms per ha in some parts of Karnataka to highly dense stands of nearly 400 palms per ha in the Lakshadweep islands.

The country's coconut industry suffers from two main problems: Root (wilt) disease, which is a major constraint crippling the coconut production in central and southern districts of Kerala; and drought, as the crop is mainly grown as rainfed crop or with limited irrigation. In addition, Eriophyid mite has become a serious threat to coconut cultivation in recent years. Price fluctuation for coconut and its products is also another threat to coconut farmers.

India has a relatively well-developed coconut R&D network that supports coconut farmers and the industry in general. The Central Plantations Crops Research Institute (CPCRI) and many state agricultural universities concentrate on research at the national and regional levels. An All India Coordinated Research Project on Palms (AICRPP) plays a crucial role in networking these organizations. The Coconut Development Coir Board helps in implementing developmental programmes on coconut and coir, in collaboration with the state departments of agriculture, horticulture and oilseeds.

Genetic enhancement for crop productivity is an important activity of the concerned research organizations, particularly by the CPCRI, which spearheads coconut research and development in the country.

Germplasm collecting work in the country dates back to 1916, initiated by the Central Coconut Research Station, CPCRI's forerunner.

Research activities and outputs

Genetic improvement of coconut is carried out by systematic research on collecting, evaluating, conserving and utilizing coconut diversity within the country and abroad. Hybridization programmes evaluate various hybrid combinations for increased yield. Genotypes are screened simultaneously for tolerance to biotic and abiotic stress and other desirable traits. The genetic architecture of coconut is also being investigated using the half diallel experiments. Floral biology and mating system are being studied in all accessions. Considering these research activities, coconut breeding in India is geared to meet the growing needs of coconut growers and the industry.

Collecting

CPCRI maintains the world's largest coconut germplasm collection, comprising of 86 exotic and 46 indigenous cultivars. The exotic collection from 22 countries of South, Southeast Asia, Caribbean, the Pacific Islands and Africa consist of 68 Talls, 16 Dwarfs, one semi-dwarf and one hybrid. The indigenous collection, on the other hand, consists of 34 Talls and 12 Dwarfs. Sub-samples of these collections are also maintained at 10 different centres under AICRPP.

Under the ADB Phase 1 project of the International Coconut Genetic Resources Network (COGENT), germplasm collecting was undertaken from the three Indian Ocean islands of Seychelles, Madagascar and Mauritius. Fifteen accessions were collected in the form of embryos. Under the subsequent ADB Phase II project, eight accessions were collected from Maldives and another eight accessions from the islands of Comoros and Reunion. Eleven accessions from Bangladesh and four accessions from Sri Lanka were later added to the germplasm holding.

Locally, under the National Agricultural Technology Project (NATP), collecting within the country was intensified in recent years, with a focus on Andaman and Nicobar Islands and the Lakshadweep islands. Extensive surveys and collecting of coconut germplasm were also undertaken in the states of Kerala, Orissa, West Bengal, Tamil Nadu, Goa, Maharashtra and Assam. At present, the national coconut genebank has been enriched with many new accessions native to India and the Indian Ocean islands, putting the total collection at 313 accessions (221 indigenous and 92 exotic accessions).

Off-shore quarantine

One of the main problems facing coconut importers is the risk of introducing foreign pests and diseases into the country. Following are some of the more prominent and potentially dangerous pests and diseases: 1) Cadang Cadang viroid; 2) Tinangaja viroid disease; 3) Coconut foliar decay virus; 4) Lethal yellowing caused by phytoplasma; 5) Red ring disease caused by nematode; and 6) Kalimantan wilt.

To prevent introduction and spread of these, CPCRI has established an offshore station in the Andamans (The World Coconut Germplasm Centre) where all exotic collections are planted. The palms are under strict surveillance in the field for the occurrence of pests and diseases for more than five years. Only nuts from healthy and disease free palms are brought to the mainland for inclusion in the genebank.

Characterization and documentation

About 74 accessions have been characterized using various descriptors and have been published in print and in electronic (CD-ROM) forms. Descriptions of these accessions with brief notes per the International Plant Genetic Resources Institute (IPGRI)/COGENT specifications have also been completed. Passport and characterization data have also been submitted to the Centre Institut de Recherche Agronomique pour le Développement (CIRAD) and shared with COGENT member countries through the International Coconut Genetic Resources Database (CGRD).

Floral biology of 80 accessions were analysed for diversity using principal component analysis (Ratnambal *et al.* 2003), which showed that St. Kudat, is different from others being a spicata form from Indonesia. Spicata is a mutant form, with unbranched inflorescence and produces more female flowers than male. In addition, the principal component analysis of morphological traits has been found to be useful in identifying mutant forms in coconuts. Coco Gra Tall, a mutant form with jelly like endosperm, was found to be quite different from the other 15 accessions native to three Indian Ocean islands (Kumaran *et al.* 1999).

Under the NATP and in collaboration with the Department of Biotechnology of the Government of India and COGENT, biochemical and molecular characterization of coconut genotypes has been initiated at CPCRI. Molecular markers are being used in characterizing coconut germplasm, specifically using RAPD markers (Upadyay *et al.* 2000). AFLP markers are being standardized for tagging root (wilt) tolerance genes. Recently, eight SSR microsatellite primers have been used in characterizing 40 germplasm accessions.

Morphological traits of mutant forms of coconut (androgena, bi-spatheate, etc.) have been characterized (Arunachalam *et al.* 2001).

Variations in foliar polyphenols content, allozyme polymorphism for esterase, peroxidase, MDH, AAADH, GOT were also determined.

A computer programme (CADMS) has been developed at CPCRI's Kayangulam Regional Station to manage the data of a pollination programme being carried out at different villages to produce root (wilt) disease-tolerant planting materials. A bioinformatics centre is also being operated at CPCRI Kasaragod, which caters to information and training needs as well as assists in digitizing the various documents in coconut literature. More details about the initiative could be found online at http://www.bioinfcpcri.org.

Conservation of coconut genetic resources

CPCRI is mandated to oversee the operation of the COGENT's International Coconut Genebank for South Asia (ICG-SA) because of its national role in coconut research, its competence in terms of technical staff, laboratory facilities and germplasm collection management capability in its various stations. The present germplasm collection contains a compact block of about 100 palms of each accession, which would hold enough population for further study and supply germplasm to other member countries as requested. With this objective, priority was given to planting the conserved germplasm (Table 1) in the ICG-SA. As a long-term storage method, cryopreservation of coconut embryos has also been standardized at CPCRI.

Utilization

The germplasm obtained from India and foreign sources are being utilized in the different breeding programmes of the country. Details of the varieties and hybrids released for cultivation are given in Tables 2 and 3.

CGD palms in 'hotspot' areas of root (wilt) disease serve as a means to evolve elite high-yielding planting materials tolerant to the disease in the region. Khan *et al.* (2002) found that Fiji Tall was the most stable variety among the six coconut varieties tested in three sites representing different agroclimatic zones.

Four hybrids involving direct crosses between WCT and COD were planted with four replications with six palms per plot in CPCRI under rainfed condition. Tall x Dwarf hybrids produced significantly higher cumulative nut yield, average nut yield and average number of female flowers per year.

Poverty reduction and *in situ* conservation

Poverty has always been intertwined with plant genetic diversity. In order to address the twin issues of poverty and *in situ* conservation, IPGRI-

Table 1. Cultivars conserved at the ICG-SA

Andaman Giant	Barajaguli Tall	Car Nicobar
Andaman Ordinary	Benaulim Tall	Ceylon Tall
Andaman Ranguchan	Blanchissuse	Chandan Nagar Green Tall
Arasampati Tall	Borneo	Chowghat Green Dwarf
Auck Chung	British Solomon Islands	Chowghat Orange Dwarf
Ayiramkachi	Calangute	Cochin China
	Cameroon Red Dwarf	
East Coast Tall	Kulasekharam Green Dwarf	Philippines Lono
Federated Malay States	Kulasekharam Orange Dwarf	Philippines Ordinary
Fiji Rotuma	Laccadive Micro	S.S. Apricot
Fiji Tall	Laccadive Ordinary	S.S. Green
Ghaighatta Tall	Lifou Tall	Sakhigopal
Guam I	Malayan Green Dwarf	San Ramon
Jamaican Sanblas	Malayan Orange Dwarf	Sendagan Tall
Java	Malayan Yellow Dwarf	Spicata
Kappadam	Nadora Tall	St. Vincent
Kenya Tall	Niu Hako	Standard Kudat
King coconut	Panama Tall	Tinisera
Kulasekaram Yellow Dwarf	Pao Pao	Tinisera
		Tiptur Tall
		West African Tall
		West Coast Tall
		Zanzibar

COGENT supported a project in three communities in India as pilot sites to help poor coconut farmers alleviate their poverty. The project included market research, feasibility studies on intercrops in a coconut-based farming system, identification of high-yielding and adapted farmer's varieties, and implementation of village-level, income-generating coconut-based processing technologies. Presently, the project is being carried-out in Ariyankuppam Village at Pondicherry, and Pallikere Village of Kasaragod Kerala, under the wings of CPCRI, and in Vayalar Village of Alapuzha District of Kerala under the supervision of the Peekay Tree Crops Foundation, a developmental non-government organization.

Community-managed nurseries, which have been established in these sites, serve the twin needs of supplying the planting material demand of farmers as well the on-farm conservation of the local farmers' varieties. Characterization of these landraces and farmers' varieties along with farmer-identified diversity has been completed with the help of diversity fairs organized in these villages.

Table 2. Field performance of released coconut cultivars

Cultivar	Yield (nuts/palm/year)	Copra yield (g/nut)
Chandra Kalpa (Laccadive Ordinary)	98	195
Pratap (Banawali Green Round)	151	160
Philippines Ordinary (Kera Chandra) (Double Century)	110	198
VPM 3 (Andaman Ordinary)	92	162
Kamrup (Assam Tall)	106	162
Aliyarnagar 1	126	
Chowghat Orange Dwarf	62	
Local Tall (West Coast Tall)	80	180

Table 3. Field performance of released coconut hybrids

Hybrids	Annual nut yield/palm	Annual copra yield			Oil content (%)	State where recommended
		g/nut	kg/ palm	t/ha		
Chandra Sankara (COD x WCT)	116	215	25	4.4	68.0	Kerala, Tamil Nadu and Karnataka
Kera Sankara (WCT x COD)	108	187	21	3.5	68.0	Kerala and Karnataka
Chandra Laksha (LCT x COD)	109	195	21	3.7	69.0	Kerala and Karnataka
Laksha Ganga (LCT x GBGD)	108	195	21	3.7	70.0	Kerala
Ananda Ganga (ADOT x GBGD)	95	216	21	3.6	68.0	Kerala
Kera Ganga (WCT xGBGD)	100	201	21	3.5	69.0	Kerala
Kera Sree (WCT x MYD)	112	216	24	4.2	66.0	Kerala
Kera Sowbagya (WCT x SSAT)	130	195	25	4.3	65.0	Kerala
VHC-1 (ECT x MGD)	98	135	13	2.3	70.0	Tamil Nadu
VHC-2 (ECT x MYD)	107	152	16	2.9	69.0	Tamil Nadu
VHC-3 (ECT x MOD)	156	162	25.2	3.5	64.5	Tamil Nadu
Godhavari Ganga (ECT x GBGD)	140	150	21	3.7	68.0	Andhra Pradesh
WCT (Control)	80	176	14	2.5	68.0	

***Legend**: COD = Chowghat Orange Dwarf, WCT =West Coast Tall, LCT =Laccadive Ordinary Tall GBGD = Gangabondom Green Dwarf, ADOT =Andaman Ordinary Tall, MYD =Malayan Yellow Dwarf, SSAT = Straight Settlement Apricot Tall, ECT =East Coast Tall, MGD =Malayan Green Dwarf, MOD =Malayan Orange Dwarf*

Significance of research results

Results of the research work on genetic resources indicate the tremendous value of germplasm diversity in development. Collecting missions resulted in more than doubling of the germplasm holding. This broadened genetic base fulfils the future needs for developing coconut genotypes tolerant to biotic and abiotic stresses and suitable for producing diversified high-value products. By hosting the ICG for South Asia, India's role in assisting regional partners has significantly increased.

Documentation of coconut germplasm carried out so far has resulted in documenting relevant data that could be used by coconut breeders and researchers to further develop the coconut genetic resources of the country in more meaningful ways than it used to be.

Conservation strategies implemented within a poverty reduction context not only preserve valuable coconut resources material for future endeavours but also provide a concrete link between improving coconut farmers' lives with germplasm conservation.

Suggested next steps

Coconut genetic research in India, with CPCRI at the helm, would focus on the following R & D activities within the next few years:

1. Development of more high-yielding varieties;
2. Development of suitable varieties for rainfed farming situations;
3. Development of drought-tolerant varieties;
4. Development of varieties tolerant to root (wilt) diseases;
5. Development of varieties tolerant to other biotic and abiotic stresses;
6. Development of varieties that are suitable for tendernut production and other products;
7. Conduct of further genetic studies to understand the combining ability, gene action and heterosis for yield and other economic traits;
8. Conduct of studies to understand the floral biology of various coconut accessions;
9. In-depth analysis of the diversity of coconut accessions using morphometric, molecular and biochemical markers;
10. Development of suitable varieties under the different agro-climatic zones of India; and
11. Continue and expand support to the ICG.

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South Asia
Status of coconut genetic resources research in Sri Lanka

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Introduction

Coconut is the most widespread plantation crop in Sri Lanka, occupying 20% of the cultivated land area. The total extent under coconut cultivation is approximately 443 000 hectares. About 65-70% of the land is confined to the coconut triangle encompassing the Kurunegala, Gampaha, Colombo and Puttalam Districts.

Coconut is essentially a smallholder crop, with 80% of smallholdings ranging from 2-4 ha. Coconut is also grown in home gardens. Annual coconut production in Sri Lanka fluctuates within the range of 2500 - 3000M nuts. Of the total production, 70% is being consumed locally and the balance available for coconut-based processing industries. Per capita consumption of coconut in Sri Lanka is about 115 nuts per annum, making it one of the highest per capita coconut consuming countries in the world.

Coconut is grown widely under rainfed conditions and as a result national production largely depends on the annual rainfall pattern. The most widely grown coconut cultivar is ordinary Tall (typical). The coconut breeding programme has been in operation since the inception of the Coconut Research Institute (CRISL) in 1929. The local Tall, being a predominantly out-breeding crop with a long generation interval, and in the absence of a proven method of vegetative propagation, mass selection and hybridisation have been the major tools used in coconut breeding in the country. Genetic improvement of coconut varieties had commenced in early 1940's by crossing selected Sri Lanka Talls to produce the improved cultivars Tall x Tall (CRIC 60). Subsequently, production program was also initiated concomitantly which produced the Dwarf x Tall hybrid (CRIC 61), first introduced in 1965. The first isolated seed garden for the mass production of improved cultivar CRIC 60 was established in 1955. The coconut biotechnology programme was initiated at CRISL in early 1970's. The Tissue Culture Research Programme was also developed as a successful embryo culture technique for germination of Dikiri Coconut, a high-priced soft endosperm coconut.

Various projects carried out with the assistance of the International Coconut Genetic Resources Network (COGENT) to complement the existing coconut breeding programme of the institute are discussed in this article.

Acceleration of collecting and conservation of the coconut biodiversity at risk in Sri Lanka and evaluation of the existing coconut populations for physiological adaptation and setting up of *in situ* germplasm repositories at eco bank (*WMU Fernando, 1 August 1994 – 31 July 1997*)

Importance of the problem
There had been tremendous genetic erosion in coconut due to rapid industrialization/urbanization that took place in the major coconut growing areas of the country. Natural disasters such as cyclones and droughts have also contributed to the loss of vital genetic material in coconut. Therefore, the urgent need was to collect and conserve as much diversity as possible within the country and utilize them more efficiently in coconut breeding.

Problems and opportunities addressed
This project aimed to accelerate the ongoing conservation programme with the view to conserve representative samples of all populations found worth conserving, especially populations showing drought tolerance with a view to include them in the breeding programme. It also aimed to set up of *ex situ* genebanks in order to supplement the national regeneration and reproduction programme.

Results or outputs of the activity
Based on random sampling, seven representative accessions were collected from seven target provinces. In the process of biased sampling, special emphasis was made on drought tolerance. A total of 20 accessions from drought prone areas that withstood severe droughts and three introduced populations were collected. Both materials collected as random and biased samples were established in a third germplasm repository consisting of 16 accessions. Maintenance and data collection of the duplicate genebanks that were established during 1989-90 was carried out successfully and data submitted for inclusion in COGENT's coconut genetic resources database (CGRD) was also updated. A systematic germplasm evaluation trial consisting of nine distinct germplasm accessions with 15 halfsib families per accession was established during the project period. Four different progenies resulting from crosses between putative drought tolerant germplasm accessions and Ambakelle Tall were

established in a range of agroecological conditions in order to evaluate their potential.

Significance of the results and their impacts to the identified problem

The project selected populations that are putatively adapted to the respective agroecology within the area, evaluated existing populations for physiological adaptation, and set up *in situ* germplasm repositories or ecobanks. Two types of populations were selected in the process and a total of 10 populations were conserved for *in situ* conservation and to provide seednuts for the National Replanting Programme. This would strengthen the replanting programme of the country by providing diversity to the existing improved cultivars. Five samples were from 10% of the population from large estate populations in order to provide seed material for their own planting programmes.

Suggested next steps

Arrangements have been made to study drought tolerance using the materials collected using RAPD analyses, physiological drought tolerant parameters and *in-vitro* screening of embryos under drought simulated conditions.

RAPD-based characterization of conserved coconut bio-diversity in Sri Lanka with emphasis on detection of markers linked to drought tolerance *(JMDT Everard, LK Weerakoon, CS Ranasinghe, 1998-2001*)

Importance of the problem

The main component of the project was to develop RAPDs among coconuts in Sri Lanka, that vary widely in their ability to withstand moisture stress, with the long term objective of tagging molecular markers for drought tolerance for use in marker-assisted breeding.

Problems and opportunities addressed

The specific objectives of the project were to screen the 20 individuals each of 20 coconut germplasm accessions in the RAPD-PCR and detect as many polymorphisms as possible while developing physiological and *in-vitro* descriptors for measuring the level of drought tolerance in each accession. Physiological parameters investigated are net assimilation rate, stomatal diffusive resistance, leaf water potential and abscisic acid content in the xylem sap. Tolerance of *in vitro* cultures to different levels of polyethylene glycol was investigated as another indicator of drought tolerance. In addition coconut germplasm conservation programme was also extended to expand the number of accessions conserved *ex-situ*.

Results or outputs of the activity

A total of 100 primers were generated and subsequently the best 20 out of them were used to detect markers to distinguish the 20 coconut accessions. RAPD profiles obtained revealed 84 strong polymorphic bands and when these are initially analysed, the genetic relatedness of 20 accessions studied showed clear separation of populations into three groups. The first constituted all Sri Lankan Tall accessions, the second comprised San Ramon and Dwarf types and the third, hybrids of the above two groups. However, as typical of the RAPD technique, most of the polymorphisms did not appear consistently when assayed in individuals. Therefore, three individuals from each group were subjected for rigorous screening to obtain best RAPD markers with minimal cost. This revealed 54 polymorphisms unique to any one or two of the three groups assayed.

Under physiological and biochemical screening, it was possible to separate the accessions into three groups: high, medium and low in terms of the evaluarion parameters but the results were not conclusive due in part to poor correlation of the parameters. *In-vitro* screening results clearly showed the high susceptibility of dwarf types to drought. The hybrids are slightly better while Tall types were the best having the highest level of drought tolerance. The collecting, conservation, evaluation and utilization of coconut were continued at a rapid pace, adding 20 more accessions to the collection.

Significance of the results and their impacts to the identified problem

The project established F_2 populations for carrying out segregation analysis to find linkage between molecular markers and traits of drought tolerance. Already established F_2 population now serves as the base population of mapping the coconut genome by RAPDs, as well as, microsatellite polymorphisms that are being studied extensively. These findings lead to developing a genome mapping programme and inclusion of useful physiological and *in-vitro* parameters as descriptors for characterization of coconut germplasm. Utilization of the conserved germplasm in general have a very high potential as breeders' material and for those with more specific economic traits, for income generation of coconut growers.

Catalogue on conserved coconut germplasm in Sri Lanka *(JMDT Everard, 1999-2001)*

A systematic programme for conservation of coconut germplasm was initiated in Sri Lanka in 1984 and for over a 16-year period, 90 distinct phenotypes and various ecotypes have been collected and conserved *ex-situ* in CRISL genebanks. Even though various data in accordance with coconut descriptors have already been collected, they were not in a proper database format. Therefore under this project, the data was submitted to COGENT's CGRD for rapid, reliable and efficient information storage and retrieval to assist in the utilization of germplasm worldwide.

The catalogue comprises a pictorial description and a small resume of coconut genetic resources conserved *ex-situ* at CRISL.

Farmer participatory characterization of farmers' coconut varieties *(JMDT Everard,* February - September 2003)

Importance of the problem and opportunities addressed

Conservation of coconut germplasm in Sri Lanka in the past has been mainly focused on *ex-situ* conservation of morphologically diverse collections and randomly identified collections from the different parts of the country. Not much emphasis was given to the identification and conservation of farmers' collections. To sustain coconut production and increase income of coconut farmers as a means of poverty reduction in rural farmers and among women, a strong need emerged to find coconut varieties with greater adaptability, pest and disease resistance, high-value uses and other desirable characters. The appropriate approach for identification of such varieties is the participation of farmers who have an intimate knowledge about the values of their cultivars and how they could be grown for sustainable production. Such an approach provides researchers and farmers the opportunity to learn together and extract indigenous information for implementing poverty reduction initiatives.

The three sites selected for the COGENT-assisted poverty reduction project: Wilpotha, Hettipola and Dodanduwa comprise rural communities where coconut play a major role in the livelihood of villagers either as a main or supporting income source. In these communities people hardly utilize the potential of coconut as a multiple income source. Leaf bract-based products in Wilpotha and coir products in Dodanduwa are the only other uses of coconut noted in these communities at the initiation of the project. The villagers had very little concern about the diversity of coconut in their localities since Sri Lanka Tall, the most commonly found coconut in Sri Lanka, shows very little variation in terms of tree morphology and nut yield. However, whether farmers have any preference for obtaining coconut seeds or a seedling for planting from any locality or even a particular land, and reasons for such, is worth investigating.

The study aimed to characterize existing coconut varieties in the community from the point of view of the local farmers, ecology and uses; identify the different uses and products derived by the local farmers from the coconut; document the existing coconut farming system(s) in the community and commonly used coconut cultivation systems; identify the most preferred traits and non-preferred traits; identify local problems faced by the farmers regarding their coconuts and solutions employed or proposed; identify opportunities from coconut that can benefit the farmers; and develop a catalogue of farmers' varieties, a database of farmer's varieties and use value.

Results or outputs of the activity
The farmers did not identify any specific location or a population of the coconut in the Dodanduwa area as special. Hence, a single population named Dadalla was considered as a representative population. In addition, four new phenotypes of Sri Lanka coconuts were identified such as Ran Pol, Thatin pol, Juan pol and Bothal thembili during the survey. The farmers were able to identify three populations of Sri Lanka Tall, Kubuke pol, Kadawala pol and Muhuriya pol, as varieties of choice for planting at Wilpotha area. The same way, three varieties known as Nuwarakelle pol, Tharana pol and Wariya pol were identied from Hettipola area for planting.

Significance of the results and their impacts to the identified problem
The study generated useful results on farmers' perspective of coconut cultivation and uses. The strong need for better caring of coconut and utilization of many uses of coconut arose from the study in all the three pilot communities. Conservation of coconut diversity through farmers' point of view was also identified as important. Rural farmers are reluctant to grow high yielding coconuts with high or adequate inputs. *Ex-situ* and *in-situ* conservation of farmers' varieties appeared very important since they have very important traits which could be used in breeding.

Suggested next steps
It appears that the identified forms of coconut are vastly different from Sri Lanka Tall and that they are worthy candidates for heterosis breeding. It is worth characterizing them using molecular markers to identify how different they are from the local Tall coconut.

Enhancing the income and employment opportunities in the coconut sector, through conservation and sustainable use of special coconut ecotypes *(CS Ranasinghe, WMU Fernando and CK Bandaranayake, August 1998 - August 2000*)

Component 1: Identification, multiplication, collection and *in situ* conservation of thembili (King coconut) germplasm showing uniform bearing and favourable biochemical constituents for industrial utilization.

Component 2: Development of technology to improve the shelf-life of Thembili (king coconut) to cater to the overseas market.

Component 3: Farmer-participatory survey to identify multipurpose uses of coconut, suitable varieties and production constraints.

Importance of the problem

King coconut (*Thembili, Cocos nucifera* var *aurantiaca*) is endemic to Sri Lanka. The nut water, or liquid endosperm of young King coconut is a nutritious, natural beverage as it is rich in sugars (mainly reducing sugars), minerals (mainly K^+), vitamins (mainly B & C) and amino acids. King coconut suffers from the disadvantage that it is seasonal in bearing, and improved planting material of this variety is lacking. Therefore, CRISL places a major emphasis in the development of an improved King coconut strain for stable yield and non-seasonal bearing in order to increase the income of the grower and intensify national production.

King coconut can be easily and economically grown in almost all the coconut growing lands in Sri Lanka. The price of a tender King coconut in the local market varies from US$ 0.05 – 0.10 and is very much higher in the overseas market (US$ 2-4). According to entrepreneurs, the nut water of young King coconut has a high market potential overseas. Furthermore, there is a higher demand for the whole King coconut compared to processed or canned King coconut water. The young nut can be successfully air-freighted in good condition to foreign markets within a day or two. For large export volumes, sea freight would be more economical, but requires 2-3 weeks shipping time. The major problem with the export of tender King coconuts is the physio-chemical changes that take place after harvest, and during the period of sea freight and transport up to the point of sale. Tender King coconuts cannot be stored more than one week at ambient temperature due to shrinkage and discolouration of the orange coloured outer skin (epicarp), the fall of perianth, fungal attack on the soft region under the perianth and decomposition of the nut water. The content of invert sugars (glucose and fructose) decreases from 5% to 1.8% and sucrose decreases from 0.16% to 0.03% within 10 days at ambient temperature (Ranasinghe *et al*. 1999). Therefore, if technology could be developed to improve the shelf-life of young King coconuts up to four to five weeks, an enormous export potential exists to generate more income for the King coconut growers.

Problems and opportunities addressed

In the attempt to promote the use of young tender coconut as a high value product for export market to enhance farmers' income, the two main problems that need to be addressed were the low production of existing King coconut plantations due to senility and seasonality in production and the short shelf-life of fresh nuts after harvesting. Therefore, the project aimed to select King coconut mother palms with desirable palatability and regular bearing potential to increase the availability of good quality planting material and to develop a suitable packaging technology to enhance the shelf-life of nuts that would retain their cosmetic appearance and taste during sea freight and at the point of sale. In addition, a farmer participatory survey was undertaken to identify multipurpose uses of coconut in different regions of the country and coconut varieties suitable for the above uses.

Results or outputs of the activity

King coconut populations showing uniformity in bearing and desirable palatability characters were identified for *in situ* conservation. Two thousand five hundred polybagged King coconut seedlings were raised from the seednuts obtained from two selected populations; Marandawila and Walahapitiya. Seedlings were provided to plant 35 sites covering 1-2 ha involving two farmer organizations. Planting was undertaken under CRISL guidance.

For shelf-life improvement, the most suitable harvesting stage (seven to eight months after pollination), disinfection method (0.6g per L Benlate), temperature range for storage (13-15°C) and wrapping material (Polypropylene cling film) were identified for improving the shelf-life of young King coconuts for up to a period of 28-30 days. The commercial viability of the technology was confirmed *via* a trial shipment and a simulated shipment. A simple tool (tender coconut punch) for opening the tender nut was developed by the CRISL in collaboration with National Engineering Research and Development Centre of Sri Lanka (NERD).

A catalogue of farmers' varieties identified was developed and *in-situ* conservation of these varieties was encouraged. Two compendia on multiple uses of coconut and coconut food recipes were prepared.

Significance of the results and their impacts to the identified problem

Good quality King coconut seedlings (non seasonal in bearing and desirable palatability) provided to growers for on-farm conservation will be used as main sources of King coconuts for export market. There is a good demand for the shelf-life improvement technology. More than 60 coconut growers have obtained the technology from CRISL. They wanted to send tender King coconut or green coconuts to several destinations such as Japan, Korea, Middle East countries, United Kingdom, Netherlands, USA, etc. via sea freight. Data collected on farmers' coconut varieties and their multiple uses were included in COGENT's CGRD. The details on multiple uses of coconut, and the people who are involved in different industries were used as a source of basic information for ongoing COGENT funded project on poverty reduction.

Suggested next steps
- Monitor the performance of progenies from selected King coconut mother palms planted under experimental conditions and farmers' fields; and
- Improve the technology to extend the shelf-life of tender king coconuts up to eight weeks, enabling the growers to send the product to countries like USA. Experiments are in progress at the Plant Physiology Division of CRISL to achieve this target.

Coconut embryo culture research to develop effective technology for the production of coconut seedlings from the high-value soft-endosperm coconut variety "Dikiri pol" *(LK Weerakoon, March 2001 - October 2002*)

Importance of the project
Similar to Makapuno in the Philippines, Dikiri coconuts are characterized by the soft, jelly-like endosperm, which gives an added value to confectionery products. Dikiri-bearing palms are rare in the country and they are mainly confined to a small area in the southern province of Sri Lanka. In this area, Dikiri nuts are used in the confectionery industry and are highly priced. Due to the economic benefits, the farmers are keen to obtain good quality planting material to build up a population of Dikiri plants.

Embryo culture technology can be used successfully to rescue Dikiri embryos. The present project was undertaken with the aim of mass propagating Dikiri coconut using the COGENT upgraded coconut embryo culture protocol. Attempts were made to maximize recovery of Dikiri embryos and minimize losses to ensure rapid distribution of good quality, robust planting material to resource-poor farmers.

Objectives of the project
1. To develop effective technology for the production of coconut seedlings from the high-value soft-endosperm coconut variety 'Dikiri pol'; and
2. Use the upgraded embryo culture technology as agreed during the

2nd International coconut embryo culture workshop in Merida, Mexico in March 2000 or any suitable modifications.

Activities conducted (Culture initiation and maintenance)
Mature Dikiri nuts (11-12 months after pollination) were collected from palms in the Weligama area. The embryos were excised from the kernel and after sterilization; they were cultured in glass test tubes containing 10 ml of growth medium. The COGENT upgraded coconut embryo culture protocol was used for initiation and maintenance of Dikiri embryo cultures. When spontaneous rooting did not occur, the shoots were dipped in a solution of Indoleacetic acid (IAA; 100 mM) for three days followed by culture in an auxin-free medium, to induce rooting. The embryos that did not germinate and the embryos that did not grow further after sprouting were treated with GA_3 (0.35 mM). GA_3 was incorporated into the liquid culture medium and the embryos were kept in this medium until germination and further growth. Then they were transferred to standard growth medium devoid of GA_3. For acclimatization of *in vitro*-raised Dikiri plants, the procedure that is routinely used at CRISL was followed. The germination percentage of cultured embryos, growth parameters of *in vitro*-raised plants and the rate of *ex vitro* survival were recorded.

Results and outputs
A total of 483 Dikiri embryos were cultured within the reporting period. The germination percentage varied in different batches of embryos cultured from 87.4% to 63.6 %. Usually, germination of embryos occurred within 5-8 weeks of culture initiation. A considerable number of ungerminated embryos could be recovered by the application of GA_3 (0.35 mM). Furthermore, some of the embryos that did not show any signs of growth after sprouting grew vigorously after GA_3 treatment. Thus, it was possible to increase the recovery rate of cultured embryos by this treatment. The *in vitro* growth of embryos at the time of transplanting was found to be satisfactory. Usually, plants could be transferred to soil within 6-9 months of culture initiation. The *ex vitro* survival of the first batch of plants transplanted in soil was low (50.6 %). This was due to a fungal attack (during initial phase of acclimatization) that resulted in the loss of 35 plants. However, the survival rate of the other plants potted was observed to be high. About 200 Dikiri plants were produced and distributed among resource-poor farmers.

Constraints
Scarcity of Dikiri nuts from non-seasonal bearing palms was a major constraint in propagating an adequate number of Dikiri plants. In a

single collecting mission, only a limited number of nuts could be collected as Dikiri palms are restricted to a small region of the country. Furthermore, severe drought conditions that prevailed in the year 2001 caused a considerable drop in coconut yield. As a result, the availability of Dikiri nuts for culture was reduced further.

Significance of the results

The main objective of the project was to produce high-value Dikiri plants using upgraded embryo culture technology. Even with the limited number of Dikiri nuts available, it was possible to produce a reasonable number of Dikiri plants that were distributed to resource-poor farmers as a poverty reduction intervention. The funds made available from the project were used mainly to improve facilities available for *in vitro* technology. It can be concluded that the project made a potential valuable contribution towards poverty alleviation through increased production of high-value Dikiri plants with the use of improved embryo culture technology.

Suggested next steps

The propagation of Dikiri plants using the above protocol will be continued to ensure a steady supply of Dikiri plants to resource-poor farmers.

Increasing the efficiency of embryo culture technology to promote coconut germplasm collection and exchange (*K Weerakoon, May 1998 - November 1999*)

Importance of the project

Collecting of coconut germplasm from other countries is an important aspect of future breeding programmes. Thus, we need to be equipped with efficient technologies for collection and exchange of germplasm. Embryo culture technology is very important in this regard as a valuable tool for efficient collecting, exchange and conservation of germplasm. It can be employed successfully to eliminate diseased stocks from germplasm material and also to cut down transport costs. Furthermore, it facilitates rescuing embryos of non-germinating and economically important types of coconut such as Dikiri. However, techniques used for *in vitro* culture of embryos and *ex vitro* hardening of resulting plants have to be optimized in order to achieve maximum possible success from recovery of embryos to field establishment. Thus, the present embryo culture protocol used at the CRISL has to be validated and refined in order to achieve the maximum possible success rate.

Objectives of the project
(1) To validate selected protocols and improve the present protocol used at the CRISL; (2) To evaluate the effect of added substrates on efficiency of weaning; and (3) To evaluate the effect of ABA and / or osmoticum and GA_3 on the maturation and germination of embryos.

Activities conducted

Preliminary studies. The 2Y3 medium (modified Eeuwens Y3 liquid medium at double strength) was routinely used at CRISL for mature zygotic embryo culture of coconut since 1985. As most of the participating countries under the DFID-funded embryo culture project use Eeuwens Y3 medium at single strength, it was decided to test the performance of embryos cultured in 2Y3 and Y3 using the cultivar Sri Lanka Tall (SLT). Germination of embryos, plant vigor at the time of soil establishment and ex vitro survival of plants raised in the two media were evaluated.

Validation of selected embryo culture protocols. Embryo culture media used at CPCRI, India, UPLB, Philippines and Sri Lanka were tested to select the best protocol. Mature embryos of the cultivar SLT and Sri Lanka Green Dwarf (SLGD) were used and the germination and subsequent growth of embryos and *ex vitro* survival of plants raised in the 4 different media were evaluated. Based on the results of experiment, Y3CRI was selected as the best protocol. Dikiri embryos were cultured in Y3CRI medium and the germination and subsequent growth of embryos and *ex vitro* survival of plants were recorded.

Addition of substrates to promote root development. An experiment was initiated (using cultivar SLT) to test the feasibility of improving the survival rate of *in vitro*-grown seedlings by the addition of several rooting substrates into the growth medium. Three different rooting substrates (coir fiber, vermiculite and absorbent cotton wool) were added to the growth medium (2Y3CRI) at the final stage of *in vitro* culture and they were tested against the control (without any rooting substrate).

Effect of GA_3 on germination of embryos. The effect of three levels of GA_3 (0.046, 0.23, 0.46 mM) on embryo germination was tested using embryos of SLT and Dikiri. Sterilization of GA_3 was done by autoclaving with the other media components. The embryos were cultured in media containing different levels of GA_3 and after four weeks, they were transferred to regular Y3CRI medium devoid of GA_3. The germination of embryos in different treatments was evaluated. In order to test whether the mode of sterilization affects the activity of GA_3, a preliminary experiment was conducted using filter sterilized GA_3.

Effect of ABA on maturation of embryos. An experiment was conducted to study the effect of ABA on maturation of embryos cultured *in vitro*. Immature nuts (9 and 10 month-old) of the cultivar SLT were used and three levels of ABA (5, 10, 20 mM) were tested against the control (without any ABA). ABA (filter sterilized) was incorporated into Y3CRI medium (both solid and liquid) and immature embryos were cultured into different treatments. The effect of each treatment on germination of embryos was evaluated. For acclimatization of *in vitro*-raised Dikiri plants, the procedure that is routinely used at CRISL was followed.

Results and outputs

Results of preliminary investigations indicated that Y3CRI medium (modified Eeuwens Y3 liquid medium at single strength) is superior to 2Y3CRI medium (modified Eeuwens Y3 liquid medium at double strength) which was used routinely at CRISL. Comparison of the three media used at CRISL (Y3), University of Philippines at Los Baños (UPLB), Philippines and Central Plantation Crops Research Institute (CPCRI), India using the cultivar, Sri Lanka Tall (SLT) revealed that percentage embryo germination, mean number of leaves/plant, percentage of plants potted and survival of plants were not significantly different for the three media. However, the mean number of roots/plant was significantly higher in Y3CRI medium than in the other two media. The growth of Dikiri embryos in Y3CRI medium was found to be satisfactory. The preliminary results did not indicate any positive effect on root formation by the addition of rooting substrates. No significant difference in embryo germination was observed when mature embryos of SLT and Dikiri were treated with 0.046, 0.23 and 0.46 mM of GA_3 sterilized by autoclaving. However, treatment of mature embryos of Dikiri with filter-sterilized GA_3 at 0.23 mM markedly increased in embryo germination. Preliminary results indicated that ABA has a positive effect on maturation of embryos, when incorporated into solid medium.

Constraints

Scarcity of Dikiri nuts was a major constraint in conducting experiments with this particular cultivar. Thus, the number of Dikiri embryos allocated per treatment was low. This could have contributed to the high variation observed in some of the experiments. High palm-to-palm variation and variation within a bunch is inherent to coconut. This factor also contributes to high coefficient of variation in certain experiments which could some times mask the actual effect of certain treatments. High contamination rates observed in certain experiments was also a problem in evaluating the effects of various treatments. Due to heavy contamination, some of the embryos had to be discarded. This resulted in a reduction in the number of embryos available for evaluation.

Significance of the results

The main objective of the project was to validate and refine current embryo culture protocol used at CRISL specially to be used for germplasm collecting and exchange. The experiments carried out during the project gave rise to important findings that could be applied to increase the efficiency of the CRISL protocol.

The embryo culture medium that was used routinely at CRISL (before commencing the present project) was 2Y3CRI. However, Y3CRI medium was shown to be much better. With the use of Y3CRI medium, it was possible to improve the *in vitro* growth and *ex vitro* survival of plants. When the Y3CRI medium was compared with CPCRI and UPLB media, there was no significant difference in most of the parameters tested.

Another important finding of the project was the positive effect of GA_3 on embryo germination especially when filter-sterilized GA_3 was used. This finding will make a significant contribution towards the improvement of the current embryo culture protocol to maximize the recovery of desired embryos.

The preliminary results on the effect of ABA on embryo maturation also indicate the possibility of *in vitro* maturation of immature embryos with the use of ABA. This could lead to the recovery of embryos from immature nuts and enables capturing of maximum variability within populations. It can be concluded that the findings of this project was very valuable in improving the current embryo culture protocol used at CRISL.

Suggested next steps

Mature embryos from several different varieties of coconut were brought to Sri Lanka from India and PNG. The improved coconut embryo culture protocol was used in raising these plants under *in vitro* conditions. Furthermore, arrangements have already been made to bring coconut germplasm from Cote d'Ivoire as well.

Poverty reduction in coconut growing communities (*Ajith Samarajeewa and Sumith Senarathne, 2000 – 2005*)

Activities

To increase incomes of coconut farmers, CRI participated in COGENT's diversity-linked 'Poverty reduction in coconut growing communities' project, involving eight Asia Pacific countries. The project deployed and tested four income-generating technologies on: 1) production and marketing of high-value products from all parts of the coconut; 2) intercropping cash and food security crop; 3) livestock raising and feed/fodder production; and 4) establishment of community-managed seedling nurseries. The project was implemented in three coconut growing communities, namely Wilpotha, Hettipola and Dodanduwa. The project involved 168 participants in production of high-value coconut products, 328 in intercropping and 197 in animal/fodder production.

Significance of the project

The project increased the incomes of participants by 2- 5 times, enhanced their food security and nutrition, and more than 3500 coconut seedlings conserved on farm. A follow up project using the same strategy and technologies was supported starting in 2005 to help tsunami victims in Dodanduwa.

South Asia

Status of coconut genetic resources research in Bangladesh

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Introduction

In Bangladesh, coconut is considered as a crop with high economic importance because of its variety of uses. The crop is commonly grown in homesteads following a unique farming system that makes effective and efficient utilization of land. Many households, which are generally smallholders, depend on the coconut for their livelihood as it provides regular income to growers (Eyzaguirre and Batugal 1999). Bangladeshi Typica is the coconut variety commonly grown throughout the country, which takes about six to eight years to flower and bear fruits after planting (Tabibullah 1976; Ahmed 1982 and Rashid *et al*. 1987). The Typica has acceptable nut quality and yield consistency (Islam 2002). Bangladesh Agricultural Research Institute (BARI) collected coconut germplasm from home and abroad for research. Although, BARI recommended two coconut varieties, BARI Narikel-1 and BARI Narikel-2, in 1996 for general cultivation throughout the country, information on genetic diversity of coconut of Bangladesh is meagre.

The southern part of the country contributes about 80% of total production (BBS 2002). The national yield of coconut has been estimated at 21 nuts/palm/year with a total production of 90 000 tonnes/year from 30 000 ha planted to coconut (BBS 2002). Islam (2002) reported that around 44% of production is consumed as tendernut and 40% as mature nut for fresh consumption. Only 9% is processed in industries while 7% is used for seedling purposes.

The maximization of income opportunities from coconut is being hindered by the low productivity of coconut trees due to lack of diversified uses, inadequate processing facilities and absence of community-based organizations (CBOs) in coconut growing communities to establish village level affordable processing units. Investing in village-level coconut processing industries is considered risky because of inconsistent and low nut production. However, in collaboration with the International Coconut Genetic Resources Network (COGENT) of the International Plant Genetic Resources Institute (IPGRI), some of these constraints are being overcome.

Research activities supported by COGENT

Collecting characterization and conservation of coconut germplasm in Bangladesh (1999-2001)

Infrastructure, such as land and human resources for coconut research in Bangladesh is not adequate. Although, coarse grid sampling method was used and 26 populations characterized *in situ* before collecting seednuts, under limited resources conditions, only 10 to 30 seedlings of each population could be collected and planted for *ex situ* conservation in the BARI Research Stations. The genotypes identified, according to the place of collections, are shown in Table 1.

Table 1. Population name with geographical locations of identified sample sites for *in-situ* characterization and collecting of coconut germplasms in Bangladesh

Population	Accession	Accession size	Accepted abbreviation	Location on coarse grid map	Latitude	Longitude
Babugonj Tall	BG0015	30	BBGT	G7S1	22°48´	90°18´
Uzirpur Tall	BG0016	30	UZT	G7S2	22° 50´	90° 15´
Agailjhara Tall	BG0017	30	AGT	F7S1	22° 58´	90° 12´
Swarupkathi Tall	BG0018	30	SWT	F6S1	22° 43´	90° 02´
Jhalakathi Tall	BG0019	30	JLKT	F6S2	22° 40´	90° 40´
Kalapara Tall	BG0020	30	KPAT	G6S1	21° 0´	90° 15´
Lebukhali Tall	BG0021	30	LBUT	G6S2	22° 27´	90° 27´
Bhola Tall	BG0022	30	BHOLT	H6S1	22° 21´	90° 52´
Kayemkola Tall	BG0023	30	KAKOT	D7S1	23° 08´	89° 50´
Bagharpara Tall	BG0024	30	BGPT	D7S3	23° 19´	89° 19´
Jhenaidah Tall	BG0025	30	JHDT	D8S1	23° 36´	89° .76´
Kushtia Tall	BG0026	30	KUST	D9S1	23° 59´	89° 06´
Atkapalia Tall	BG0027	30	ATKPT	I7S1	22° 16´	91°04´
Buikara	BG0028	30	BUKT	D7S2	23° 14´	89° 52´
Manikgonj Tall	BG0029	30	MNGT	F10S1	23° 49´	89° 58´
Sherpur Tall	BG0030	30	SPRT	F13S1	25° 0´	90° 01´
Muktagacha Tall	BG0031	30	MKGT	G12S1	24° 48´	90° 07´
Goffargoan	BG0032	30	GFGT	G11S1	24° 28´	90° 36´
Chinashukhania	BG0033	30	CHNST	G11S2	24° 11´	90° 24´
Puthia Tall	BG0034	30	PUTT	C11S1	24° 24´	88° 88´
Natore Tall	BG0035	30	NATT	D11S1	24° 19´	88° 59´
Bogra Tall	BG0036	30	BOGT	D12S1	24° 48´	89° 0´
Kishoreganj	BG0037	30	KISGT	H10S1	25° 01´	89°58´
Razbari	BG0038	30	RAJT	E9S1	23° 41´	89°43´
Bagerhat	BG0039	30	BAHT	E6S1	23°06´	90° 20´
Chinasukania	BG0040	10	CHNSD	G11S2	24° 11´	90° 24´

Coconut varieties conserved in the different regional and sub-stations of BARI have also been characterized (Table 2).

Passport data of 26 collected populations as well as passport and characterization data of 14 BARI-conserved varieties have been submitted to the COGENT's International Coconut Genetic Resources Database (CGRD). Eleven populations have been deposited in the International Coconut Genebank for South Asia (ICG-SA) in India for long-term conservation and future use. A catalogue of conserved varieties in Bangladesh has been prepared and submitted to COGENT.

Table 2. Coconut germplasm conserved in different stations of BARI

Accession	Accession size	Name	Other name/ ethnic name	Accepted abbreviation	Location on coarse grid map	Latitude	Longitude	Acquisition date/Year
BG0001	400	Rahmatpur Tall Deshi	BARI Narikel-1	RGTD	G7	22°42′	90°22′	1965
BG0002	1200	Rahmatpur Tall (Malayan)	BARI Narikel-2	RGTM	G7	22°42′	90°22′	1966
BG0003	700	Rahmatpur Tall (Shinghali)	Shinghali	RGTS	G7	22°42′	90°22′	1966
BG0004	200	Rahmatpur Yellow Dwarf	Malaysian Dwarf	RYD	G7	22°42′	90°22′	1666
BG0005	300	Khairtala Tall	Deshi Narikel	KHT	D8	23°11′	89°14′	1969
BG0006	250	Rhaikhali Tall	Chandraghana	RHT	K6	22°22′	92°51′	1974
BG0007	200	Hathazari Tall	Chatgoan Tall	HGT	J6	22°17′	91°35′	1967
BG0008	35	Hathazari Red Tall	Chatgoan Red Tall	HRT	J6	22°17′	91°35′	19607
BG0009	7	Pahartali Red Tall	Chatgoan Red Tall	PRT		22°11′	91°36′	1975
BG0010	150	Jamalpur Tall	Deshi Narikel	JMT	F12	24°56′	89°55′	1968
BG0011	200	Iswardi Tall	Deshi Narikel	ISDT	D10	24°08′	89°02′	1966
BG0012	150	Poilanpur Tall	Deshi Narikel	POT	D10	24°2.6′	89°02′	1974
BG0013	250	Ramgarh Tall	Deshi Narikel	RAGHT	K8	23°38'	92°13'	1968
BG0014	300	Khagrachari Tall	Deshi Narikel	KHAGT	K8	23°10'	92°36'	1968

The information gathered so far indicates that the genotype found in Chinasukania village appears to be very different from that of Buikara and Bhola. Genotypes of Jhalakathi and Gafargaon were somewhat similar to each other. Among the varieties conserved at different BARI stations, the population of Khairtala Tall (KHAT) and BARI Narikel-2 seemed to be similar. In the early 1960s, coconut germplasm were introduced and planted in different BARI research stations, including Khairtala and Rahmatpur (Rashid 1987; Islam and Hossain 2000). Therefore, the BARI Narikel-2 and Khairtala Tall might be the same genotype. On the other hand, the populations of Jamalpur and Ishurdi Talls were found to be genetically similar to that of BARI Narikel-1. Razzaque *et al.* (2000) mentioned that BARI Narikel-1 was a selection from local coconuts. Therefore, it is possible that some similarities may exist in these three genotypes. Nevertheless, a wide range of coconut germplasm variation still exists in Bangladesh, which could be used for varietal improvement.

Identification, conservation and multiplication of tendernut varieties and pilot marketing of tendernuts

At present, green tendernuts fetch the most income to smallholders on a regular basis. Thousands of tendernuts are being used daily all over the country as drinking water, particularly during hot summer days. Farmer

Participatory Rural Appraisal (FPRA) surveys, as well as farm and home visits, were conducted to identify suitable varieties for tendernut and the constraints to its production. Market surveys on tendernut were also conducted to enhance its marketability and profitability. The studies revealed that about 44% of nuts produced per annum were used as tendernut. Yearly, about 3.07 million nuts are consumed in the capital city of Dhaka alone. On the average, coconut growers earned Tk 401.24 (US$ 6.77) per 100 nuts and consumers paid Tk 1000 (US$ 16.88) per 100 nuts. March to May is the peak period for tendernut consumption. The intermediaries in tendernut marketing include retailers, *Pharia* (people who directly collect nuts from farmers), *Bepari* (those who collect nuts from *Pharia* and farmers) and *Aratder* (persons who collect nuts from *Bepari*). Thus, the farmers are not organized and they are not able to fix the price and have no control over the markets. Hence, most of the benefits go to the intermediaries (Islam, 2002a). Government intervention is necessary to organize farmers to establish marketing chain to ensure appropriate farm price.

FPRA survey on coconut diversity

Several FPRAs were conducted in coconut growing areas of the country to identify and promote promising local ecotypes, identify opportunities to augment farmers' income and extend technical support to farmers to undertake coconut-based enterprises. Results of the FPRAs revealed that the most common variety grown in the communities was Typica and that farmers generally were not aware of other elite coconut varieties. Households consumed about 58% of the nuts produced. Lack of good planting materials, high prices of inputs, lack of diversified products as well as poor marketing channels for its products were identified as the major constraints to coconut production. The communities opined that vegetables and other high-value fruit crops could be effectively grown under coconut. Thirty-five different ways of using coconut and its parts in the communities were recorded. The absence of a marketing network was identified as the major constraint to the production and consumption of tendernuts. Farmers, in general, were not concerned about using fertilizers on their coconut palms (Islam 2002a).

Documentation of socioeconomic benefits of using local coconut varieties

The study was carried out to determine the impact of using farmer-identified local varieties on the family (1 ha model), the community (100 ha) and the ecosystem (500 ha). Two communities, in Barisal and Jessore Districts, were chosen as study sites. A total of 60 coconut farmers, 30 from each test site, were interviewed. The varieties of coconut grown by the farmers for various household uses were identified and listed. Different products and by-products from coconut and their methods of production as well as the cost-effectiveness of farm-household/ecosystem levels on the utilization of products were documented. Farm activities linked to coconut were also identified.

The study revealed that total earnings from one ecotype were estimated at Tk 37 992 000 (US$ 641 027) per year. There were six other areas in the country where similar activities were practised, generating total earnings of about Tk 227 952 000 (US$ 3 846 164) per year. In addition, other sources of income such as other crops, livestock, poultry, fish, business earned for growers about Tk 55 354 (US$ 934)/year/ha. Hence, deployment of coconut-based farming system (CBFS) at community level would help alleviate poverty (Islam 2002a).

Establishing a framework for a nationwide deployment of coconut-based poverty reduction interventions

High-yielding landraces of coconut and value-added products from the kernel, shell, husk and leaves as well as the adoption of a coconut-based farming system could increase farm income by two to three times. Extending support to undertake coconut-based enterprises is likely to increase economic activities and augment coconut cultivation. Hence, a survey was conducted in five selected coconut growing communities to identify the socioeconomic profiles of coconut growers to find out the problems and possibilities for technology intervention. The study revealed that 50 farmers from each area were selected for interview. The Typica was the only variety grown by the farmers. Variability in terms of nut colour, size and taste of tendernut were mentioned by the farmers. Per capita income of the respondents was about US$ 110, which was far below the national average of US$ 289. As per cost basic need method (income below TK 90 900 = US$ 159.49), the respondents were classified as very poor and that they need help, particularly those heavily engaged in coconut production (Islam 2002b).

Feasibility study on producing and marketing of coconut husk-based products involving women beneficiaries

Producing fibre from coconut husk is a tedious and laborious job. Husk is beaten using a wooden hammer to separate the fibre. Women and children are usually involved in making coir from the husk. Various kinds of ropes, doormats, brushes, etc. are produced from the fibre. Though it is a tedious job, there is much demand for these products in the local markets. Hence, a feasibility study on the mechanization of processing husk into coir and producing various products from it was undertaken, mainly involving women beneficiary groups. Women were trained in making various products from coir and a production system was put in place. Through these activities, the women-participants earned an average of Tk 50-60 (US$ 0.84 –1.00) per day by producing ropes and doormats. Husk from around 2000 nuts could be processed into fibre by a COGENT-supplied decorticating machine, yielding an average of 260 kg of fibre. Cost of production and income from the activity were estimated at Tk 1880 (US$ 31.72) and Tk 3250 (US$ 54.83), respectively. Return on investments (ROI) in producing fibre and doormat were 72.87% and 61.21%, respectively. Return on investment in making rope following the traditional laborious method was only 28.33% (Islam 2002a). Hence, the introduction of mechanical fibre processing unit could have a far-reaching impact on coconut fibre industry in Bangladesh. Surplus labour in agriculture sector of the country could be provided with employment by deploying new technology under the coconut based farming systems.

Adoption of COGENT-upgraded coconut embryo culture protocol in BARI

A study on the germination of coconut embryo of different ecotypes in Bangladesh was carried out at the Biotech Division of BARI. The protocol for embryo culture was standardized for two cultivars (Malayan Dwarf and an unknown ecotype). The study result has increased the recovery rate of seedlings from embryos which would enhance germplasm collecting and conservation.

Project on 'Developing Sustainable Coconut-Based Income Generating Technologies in Poor Rural Communities in Bangladesh'

To increase incomes of coconut farmers, BARI participated in COGENT's diversity-linked 'Poverty reduction in coconut growing communities' project, involving eight Asia Pacific countries. The project deployed and tested four income generating technologies on: 1) production and marketing of high-value products from all parts of the coconut; 2) intercropping cash and food security crop; 3) livestock raising and feed/fodder production; and 4) establishment of community-managed seedling nurseries. The project was implemented in three coconut growing communities, namely Bandabila, Jessore; Chandrapara, Barisal; and Jamira, Khulna. The project involved 210 participants in production of high-value coconut products, 115 in intercropping, 185 in animal/fodder production and 300 in nursery management and seedling production. The project increased the incomes of the participants by 2- 5 times, enhanced their food security and nutrition, and about 3500 coconut seedlings have been conserved on farm.

Achievements

Despite the high potential of coconut in generating income and employment, coconut smallholders in Bangladesh still suffer due to declining yields and decreasing farm productivity. Thus, there is a need to develop and disseminate improved high-yielding and adapted varieties. Farmers who own varieties with special traits were encouraged to raise seedlings of such varieties for planting in their own homestead as well as for distribution to other farmers. Interested farmers started raising the selected palms to meet the local demand. Dwarf types of natural hybrids which are resistant to pests and diseases have been identified and selected palms are being planted homesteads, especially for tendernut. Women and youth participating in the BARI-COGENT collaborative projects in Jessore and Jhenaidah districts are now earning around TK 40-50 (US$0.67-0.84) per day by making ropes and doormats, which they could not have done two years ago. At least 66 palms have been identified in different parts of the country with different outstanding attributes and farmer-owners have been convinced to maintain these genotypes in their homesteads. Community-managed nurseries have been started to raise seedlings to increase income and productivity as well as to conserve economically-important local ecotypes.

Conclusion

There is significant coconut diversity in Bangladesh and their effective utilization can enhance the incomes of small-scale farmers. Introduction and evaluation (both for adaptation as well as for economic feasibility) of certain exotic germplasm such as Makapuno would not only enhance local diversity but also help in improving the incomes of the coconut growers.

At present, the establishment of a Coconut Research Institute is urgently needed to sustain the achievements in germplasm collecting and utilization. Introduction of affordable, village-level technologies for processing coconut under the auspices of a CBO will empower communities and improve the production and marketing of different high-value products. At present, the infrastructure for research and development on coconut is not strong enough to effectively utilize modern production technologies. The potential seed multiplication garden at Ramu in Cox's Bazar District could be brought under research to maximize its utilization.

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South Asia

Status of coconut genetic resources research in Pakistan

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Introduction

Coconut is considered as one of the most important crops of the tropics. It has multiple uses and every part of the crop is used for a variety of purposes. In the early 1970s, the coconut was hardly grown on a commercial scale in Pakistan. Later on, the potential of coconut to become an economically-important crop, primarily as a source of edible oil, was realized. Thereafter, it was included in the national government's agricultural programme as a priority crop for large-scale production, especially in the coastal areas of the country.

The climatic and soil conditions in the country are not very well suited for coconut cultivation as it requires well-drained fertile soils with well-distributed rainfall under hot and humid climate. In Pakistan, the coastal belt is characterized by sandy as well as saline soils. The climate is arid with very low annual rainfall, ranging from 50 to 300 mm, and with temperature extremes. However, the area is humid enough and with proper attention and management, the crop could be successfully grown.

The coconut is not indigenous to Pakistan. The seedlings produced in nurseries came from nuts imported from other countries, most of which had no or very little information on variety or specific characters. In addition, varieties grown in the country are facing pest and disease problems. As such, research efforts on coconut in the country can be categorized under the following:

- Selection and dissemination of varieties suited to existing agroecologies;
- Orchard management practices particularly related to irrigation, fertilizer requirements and intercropping; and
- Control of pests and diseases.

Research activities conducted and outputs

Varietal selection

Although plantations of coconut have been in existence in Karachi for a long time, most of these are scattered and there is no organized plantation with known varieties. Efforts to plant coconut in organized plantations started in the late 1950s when groves were established in government farms, which continued for some time but with very little success. However, the surveys conducted by national and international agencies proved that coconut can be successfully grown in the coastal belt of Sindh and Balochistan provinces with proper management and constant irrigation as the areas are prone to drought and temperature fluctuations. The farmers in this area obtained seednuts from different countries, mainly from Sri Lanka, Bangladesh, India and Malaysia but very little or no attention was given to the specific varieties; the only thing that was considered was whether these were Talls or Dwarfs. In the late 1970s, varieties with known cultivar names and characters were imported from Sri Lanka for evaluation. The varietal screening activities were later spearheaded by the Pakistan Agricultural Research Council (PARC). After this initial evaluation, more varieties and hybrids were imported from Sri Lanka to be raised in government nurseries for distribution to farmers. The Sindh Forest Department was also involved in these activities, establishing their own plantation in forestlands near Thatta.

Results of the evaluation carried out by the two institutions recommended Tall varieties for planting as these were more tolerant to biotic and abiotic stresses and produced bigger nuts with better copra quality. However, some farmers prefer Dwarf varieties as they bear more fruits which are mainly used for coconut water and are easily marketed. At the same time, Pakistani coconut farmers do not like the Sri Lanka hybrid CRI65 as it was found to be easily damaged by stress conditions prevalent in the country. The MAWA hybrid, on the other hand, impressed some growers but could not be cultivated on larger areas because of abiotic stresses.

Orchard management

Orchard management activities focused on finding the most effective and efficient fertilizer rates for economic production. It was a general impression that the coconut does not require much fertilization and therefore, growers used only farmyard manure (FYM). Later on, trials conducted proved that application of inorganic fertilizers improved the health of palms, and decreased flower and fruit drop resulting in higher nut yield with better quality. Results showed that application of 250 g N, 100 g $P_205$and 200 g K_20 per palm was beneficial and economical for improving growth, bearing and nut quality. Addition of FYM also proved beneficial, particularly for soil improvement in slightly saline soils.

Irrigation was another important aspect under orchard management as areas planted to coconut received very low rainfall and frequently faced drought. Furthermore, many of these areas have sandy soils. To address this situation, it was recommended that crops be irrigated weekly during summer and fortnightly during winter.

It is a common practice in Pakistan to keep orchards clean and not to grow any intercrops after the trees start bearing fruits. Recent studies, however, showed that it was possible to grow vegetables as intercrops in a coconut farm as they did not affect the growth of the palms as earlier believed. It was also proven to be a profitable venture to augment the farmers' incomes.

Pests and diseases

Surveys were conducted in different coconut plantations to collect information about the existence of pests and diseases. Results of the surveys showed that the major diseases affecting coconuts in the country include root rot, bole rot, bud rot, leaf blight, stem bleeding and lethal yellowing. The intensity of these diseases greatly varied from place to place and appeared to be correlated with orchard management, the problems being more serious with poorly managed plantations. Spraying of recommended dosages and combinations of fungicides satisfactorily controlled the spread of some of these diseases, except lethal yellowing.

The insect pests damaging coconut palms in the country include termites, red palm weevil, scales, black beetle and coconut caterpillar. Initially, these pests were controlled by the use of appropriate insecticides. Surveys on the extent of damage and detailed studies related to the biology, epidemiology and control of these insect pests have not been conducted and need to be made in the future.

Very little or no work has been done on the production and marketing of alternative and high-value coconut products as overall yield was relatively small and farmers did not have problems marketing the nuts. The fruits are mainly used to extract coconut water and immature albumen. The coconut leaves are used as roofing materials while the stem has no known uses other than as firewood.

COGENT support to Pakistan's coconut programme

In 1998, COGENT supported a 3-year project to identify and characterize Pakistan's coconut genetic resources. Under this project, the coastal Agricultural Research station in Karachi identified and characterized seven coconut populations and conserved them *ex situ*. The characterization data were submitted and incorporated in COGENT's International Coconut Genetic Resources Database.

In 2000, COGENT also supported the scholarship of Abdul Hameed Solangi for Master's degrees at the University of the Philippines Los Baños. Mr Solangi successfully completed his degree which has enhanced the capability of PARC to conduct coconut research.

COGENT has also recommended that PARC conducts a thorough study for the supply and demand of coconut, a yield performance and profitability evaluation and, based on the results decide on whether to recommend the comercial production of coconut in Pakistan.

Impact of outputs and suggested future steps

Coconuts in the country are mostly grown on small scale along the coastal belt. Although there are some large plantations, most of the farmers cultivate the crop in small landholdings or on small parcels of the farm. It is estimated that on the average, farmers harvest about 40-50 nuts per tree per year. The technologies developed and introduced to farmers are expected to increase overall coconut production along with the incomes derived from it. Although coconut farmers in Pakistan are generally contented with the *status quo*, there is a need to make improvements so that the commodity can be grown on a commercial scale and that alternative high-value uses be found, developed and disseminated in order to help improve the plight of the poor farmers.

The research endeavours made so far has resulted in the improvement of coconut genetic resources but more efforts are required for its development for commercial exploitation. In particular, the following areas need priority attention:

- Introduction of high-yielding, high-value varieties suited to local climatic conditions and tolerant to biotic and abiotic stresses;
- Introduction and adoption of effective and efficient nursery and orchard management particularly on plant nutrition, intercropping and pest and disease management; and
- Utilization of nuts and other plant parts to produce alternative high-value products other than copra and coconut oil to increase farmers' income and improve their socioeconomic conditions.

Southeast and East Asia

Status of coconut genetic resources research in Indonesia

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Introduction

Indonesia, being the world's largest producer of coconut, considers the crop as a national strategic commodity. Coconut is one of the primary sources of income for most Indonesian farmers and is processed into various products like vegetable oil, raw material for food, industry, construction, medicine, cosmetic and oleochemicals. Total land area planted to coconut is about 3.7 million hectares, with 97% of overall production coming from smallholder farmers. However, in many regions of the country, productivity is declining because of old, senile palms. To address this situation, parental germplasm must be improved, new high-yielding varieties must be planted and an effective hybridization programme must be put in place.

In some regions in Indonesia, coconut genetic resources are under threat of genetic erosion due to rapid change in land utilization, natural calamities, urbanization and other economic and environmental pressures. Recent studies have indicated that the rate of genetic erosion is higher than the present conservation rate. To mitigate this, coconut genetic resources conservation through exploration, collecting and utilization must be undertaken.

Research on coconut palms was initiated during the Dutch colonial period and formal research was institutionally started in 1911. This involved collecting some coconut ecotypes in the surrounding areas of Java. From 1926 to 1927, Dr Tammes, a coconut scientist, identified and selected 100 high-yielding Tall palms from populations in the Mapanget District of North Sulawesi, which were planted at the Mapanget Experimental Garden of the Indonesia Coconut and Other Palmae Research Institute (ICOPRI). After Indonesia gained independence in 1945, coconut research activities were continued by the government. From 1956 to 1961, the Government of Indonesia contracted the services of a German FAO expert, to characterize, select and cross the coconut germplasm previously collected by Dr Tammes, with the aim of producing high-yielding hybrids.

The genetic diversity of coconut germplasm is very important in a breeding programme to improve the characteristics of coconut. The exploration of coconut germplasm in Indonesia has yielded 131 conserved accessions so far. A part of this collection has been utilized for breeding and in other research programmes to support the coconut genetic materials development programme of Indonesia.

Research activities supported by COGENT

Collecting, conserving and characterizing coconut genetic resources

The International Coconut Genetic Resources Network (COGENT) of the International Plant Genetic Resources Institute (IPGRI) supported this project in eight Asia Pacific countries, including Indonesia, where coconut genetic resources have been considered in danger of being lost because of genetic erosion. Identified germplasm were collected and conserved in each participating countries' field genebanks, augmenting and filling up gaps in their present collections. The project was funded by the Asian Development Bank (ADB) and implemented from 1996 to 1998. The research project in Indonesia specifically aimed to identify existing coconut populations in East Nusa Tenggara and Moluccas Provinces for characterization and conservation and to collect the identified germplasm materials for conservation and evaluation at the International Coconut Genebank for Southeast and East Asia (ICG-SEEA) located at Sikijang, Riau, Indonesia. During the exploration surveys at the different sites in East Nusa Tenggara, seven ecotypes consisting of six Talls and one Dwarf were selected. Results showed that the Tall populations could be categorized into three groups based on a 70% genetic resemblance. Group I consisted of Mokdale, Oenggauk, Kambaniru and Nita and Group II and III had one accession each, Namangkewa and Batutua, respectively. Nut samples from these populations were planted at the ICG-SEEA. Based on banding pattern variability of peroxidase (PER), esterase (EST) and glutamate oxaloacetate transaminase (GOT) isozymes, accessions Nita, Mokdale and Oebafok Talls from East Nusa Tenggara were different from the other Tall accessions previously collected from North Sulawesi, Kalimantan and West Sumatera. These three coconut accessions have been identified and marked for *ex situ* conservation in Sikijang.

Further exploration, collecting and evaluation of coconut germplasm

This research activity was a continuation of the activity mentioned above. A total of 20 COGENT-member countries participated, including Indonesia, with ADB funding, in a project entitled, 'Coconut genetic resources network and human resources strengthening in Asia and the Pacific region' from 1998 to 2000. The project activities in Indonesia covered Moluccas, North and Central Sulawesi and West Nusa Tenggara. Its objectives were:

1. To identify and characterize existing coconut populations;
2. To collect representative genetic materials for conservation;
3. To evaluate coconut germplasm *ex situ*; and
4. To submit generated data to the International Coconut Genetic Resources Database (CGRD) and submit the same to the Catalogue of Conserved Germplasm which is being developed by COGENT.

Fifteen coconut accessions were characterized *in situ* and collected for conservation *ex situ* at ICG-SEEA. In addition, 107 existing accessions from ICOPRI's different research stations (Mapanget - 54 accessions, Pakuwon - 20 accessions and Sikijang - 33 accessions) were characterized, and their passport and characterization data were submitted to the Centre Institut de Recherche Agronomique pour le Développement (CIRAD) and entered into the CGRD. Descriptive information on 60 accessions was documented and submitted to COGENT for the Catalogue of Conserved Germplasm.

Since 1927, exploration surveys in several provinces in Indonesia were conducted to identify and evaluate the coconut genetic diversity of the country. About 107 accessions have been collected and conserved in the four experimental gardens of ICOPRI, including the ICG-SEEA (Table 1).

In a recent survey funded by ADB, one population, Mamuaya Tall, which was collected from North Sulawesi, is now being used as genetic material for breeding and distribution in seed gardens. Presently, this population is conserved in Paniki, North Sulawesi.

Coconut embryo culture

As the host of the ICG-SEEA, Indonesia, through ICOPRI, has participated in a number of Department for International Development (DFID)- and ADB-funded activities on coconut embryo culture. DFID funded two activities, the first on 'Increasing the efficiency of embryo culture technology to promote coconut germplasm, collecting, conservation and exchange', and the second on the 'Introduction of coconut germplasm from COGENT member countries into the International Coconut Genebank for Southeast and East Asia'. It also participated in two other ADB- funded projects, namely: 'Strengthening the embryo culture capability of the ICG-SEEA' and the 'Importation and growing of designated germplasm from COGENT member countries for conservation in the ICG-SEEA'.

Table 1. Coconut accessions collected and their locations in Indonesia

No.	Accessions	Origin	Date of Planting	Surviving palms
A. Mapanget (North Sulawesi)				
Dwarf type				
1.	Nias Yellow Dwarf	North Sumatra	Feb 77	77
2.	Bali Yellow Dwarf	Bali Island	Feb 77	50
3.	Nias Green Dwarf	North Sumatra	Nov 78	65
4.	Jombang Green Dwarf	East Jawa	Nov 78	56
5.	Tebing Tinggi Dwarf	North Sumatra	Dec 79	49
6.	Malaysia red Dwarf	Malaysia	May 80	12
7.	Raja Dwarf	North Molucas	Aug 80	43
8.	Sagerat Orange Dwarf	North Molucas	May 87	18
9.	Salak Dwarf	South Kalimantan	Aug 80	46
10.	Waingapu Red Dwarf	East Nusa Tenggara	May 99	52
11.	Malaysia Yellow Dwarf	Malaysia		11
12.	Shinta red Dwarf	North Sulawesi	Seedlings	
13.	Kapal (pink husk) Dwarf	North Sulawesi	Seedlings	
Tall Type				
1.	Mapanget (Tammes collection) Tall	North Sulawesi	1927/ 1928	
2.	Takome Tall	North Molucas	May 77	51
3.	Bali Tall	Bali island	Nov 87	60
4.	Jepara Tall	Central Java	Nov 87	58
5.	Paslaten Tall	North Sulawesi	Nov 87	84
6.	Solo Tall	Central Sulawesi	Seedlings	
7.	Palapi Tall	Central Sulawesi	Seedlings	
8.	Melangoane Tall	North Sulawesi	Seedlings	
9.	Makariki Tall	North Molucas	1999	5
10.	Spikata Tall	Halmahera	1999	4
11.	Ceylon King Tall	Sri Lanka	1999	20
12.	Tenga Tall	North Sulawesi	Nov 87	87
13.	Banyuwangi Tall	East Java	Jan 79	39
14.	Sawarna Tall	North Sulawesi	Aug 80	51
15.	Mapanget No. 83 Tall	North Sulawesi	May 81	38
16.	Mapanget No. 32 Tall	North Sulawesi	July 81	39
17.	Lubuk Pakam Tall	North Sulawesi	May 81	61
18.	Aertembaga Tall	North Sulawesi	Nov 81	37
19.	Ilo-Ilo Tall	North Sulawesi	Nov 81	47
20.	Pungkol Tall	North Sulawesi	Nov 81	53
21.	Tontalete Tall	North Sulawesi	Nov 81	42
22.	Kinabutuhan Tall	North Sulawesi	Nov 81	55
23.	Talise Tall	North Sulawesi	Nov 81	21
24.	Marinsow Tall	North Sulawesi	Nov 81	35
25.	Sea Tall	North Sulawesi	Jan 82	46
26.	Kalasey Tall	North Sulawesi	Jan 82	49
27.	Wusa Tall	North Sulawesi	Jan 82	52
28.	Palu Tall	Central Sulawesi	Nov 82	52
29.	Pandu Tall	North Sulawesi	May 83	45
30.	Mapanget No. 99 Tall	North Sulawesi	May 83	50
31.	Mapanget No. 55 Tall	North Sulawesi	May 83	43
32.	Mapanget No. 2 Tall	North Sulawesi	May 83	42
33.	Igo Duku Tall	North Molucas	May 83	36
34.	Igo Bulan Tall	North Molucas	May 83	19
35.	Rennel Tall	Solomon	May 83	94
36.	West African Tall	Cote d'Ivoire	May 83	115
37.	Tahiti Tall	Polynesia	June 83	125
38.	Mamuaya Tall	North Sulawesi	May 99	66
39.	Dobo Tall	North Molucas	May 98	3
40.	Sangtombolang Tall	North Sulawesi	Oct 2000	110

No.	Accessions	Origin	Date of Planting	Surviving palms
B. Pakuwon (East Java)				
Dwarf Type				
1.	Nias Yellow Dwarf	North Sumatra	Feb 77	61
2.	Bali Yellow Dwarf	Bali Island	Feb 77	57
3.	Jombang Yellow Dwarf	East Java	Nov 78	42
4.	Jombang Green Dwarf	East Java	Nov 78	42
5.	Nias Green Dwarf	North Sumatra	Nov 78	58
6.	Malaysia Yellow Dwarf	Malaysia	May 80	67
7.	Raja Dwarf	North Molucas	Aug 80	42
8.	Salak Dwarf	South Kalimantan	Feb 88	250
	Tall Type			
1.	Boyoali Tall	Central Java	Nov 78	55
2.	Banyuwangi Tall	East Java	Nov 78	58
3.	Jepara Tall	Central Java	Nov 78	50
4.	Paslaten Tall	North Sulawesi	Apr 79	73
5.	Bali Tall	Bali Island	Apr 79	66
6.	Tenga Tall	North Sulawesi	Apr 79	71
7.	Palu Tall	Central Sulawesi	Apr 79	59
8.	Lubuk Pakam Tall	North Sulawesi	Oct 79	59
9.	Sawarna Tall	West Java	Mar 80	100
10.	Kar-Kar Tall	Papua New Guinea	Mar 80	96
11.	Markham Valley Tall	Papua New Guinea	Mar 80	100
12.	Pangandaran Tall	West Java	Aug 86	78
C. Sikijang Mati (Riau)				
Dwarf Type				
1.	Nias Yellow Dwarf	North Sulawesi	Apr 97	84
2.	Tebing Tinggi Dwarf	North Sulawesi	Apr 97	78
3.	Salak Dwarf	South Kalimantan	Apr 97	74
4.	Bali Yellow Dwarf	Bali island	Apr 97	74
5.	Raja Dwarf	North Molucas	Apr 97	50
6.	Jombang Green Dwarf	East Java	Dec 99	21
7.	Jombang Yellow Dwarf	East Java	Dec 99	23
8.	Jombang Yellow Dwarf	East Java	Dec 99	18
9.	Jombang Brown Dwarf	East Java	Dec 99	23
Tall Type				
1.	Tenga Tall (Self)	North Sulawesi	Jan 99	30
2.	Bali Tall (Self)	Bali Island	Jan 99	29
3.	Palu Tall (Self)	Central Sulawesi	Jan 99	30
4.	Sawarna Tall (Self)	West Java	Jan 99	57
5.	Mapanget Tall (Self)	North Sulawesi	Jan 99	29
6.	Wulurat Tall	Southeast Molucas	Jan 99	59
7.	Ngilngof Tall	Southeast Molucas	Jan 99	57
8.	Pulau Kelapa Tall	Southeast Molucas	Jan 99	87
9.	Togawa Tall	North Molucas	Jan 99	89
10.	Golatamo Tall	North Molucas	Jan 99	88
11.	Kumo-B Tall	North Molucas	Jan 99	58
12.	Babang Tall	Bacan Island (Molucas)	Apr 99	80
13.	Kupal Tall	Bacan Island (Molucas)	Apr 99	76
14.	Bibinoi Tall	Bacan Island (Molucas)	Apr 99	75
15.	Beber Tall	West Nusa Tenggara	Apr 99	72
16.	Ijobalit Tall	West Nusa Tenggara	Apr 99	80
17.	Tanjung Tall	West Nusa Tenggara	Apr 99	68

No.	Accessions	Origin	Date of Planting	Surviving palms
18.	Rote Tall	East Nusa Tenggara	Sept 99	90
19.	Palakahembing Tall	East Nusa Tenggara	Sept 99	82
20.	Nita Tall	East Nusa Tenggara	Sept 99	80
21.	Bawang Tall	Riau	Sept 99	11
22.	Riau (Tekulai) Tall	Riau	Sept 99	90
23.	Pangandaran Tall	West Java	Sept 99	90
24.	Klambu Buruk Tall	Riau	Sept 99	80

Increasing the efficiency of embryo culture technology to promote coconut germplasm collecting, conservation and exchange

A high percentage of mature embryos were lost due to browning. Results showed that, regardless of the variety, the highest germination and survival percentages of transplanted seedlings were noted using the University of the Philippines at Los Baños (UPLB)-developed protocol. However, Nias Yellow Dwarf (NYD) embryos registered a high germination percentage using the Central Plantation Crops Research Institute (CPCRI) medium, showing a high number of roots among surviving seedlings from *in vitro* transplants. Generally, the three coconut varieties tested responded well with the UPLB protocol, especially on the growth of germinated embryos. The incorporation of 60 ppm gibberellic acid $(GA)_3$ in the medium induced a higher percentage of germination in transplanted seedling. The introduction of abscisic acid (ABA) and GA_3 into the medium resulted in increased germination in mature embryos, but germination was lower in medium supplemented with GA_3 only.

The International Coconut Genebank for Southeast and East Asia

In its first meeting in 1992, COGENT's Steering Committee proposed the establishment of a multi-site ICG consisting of a regional genebank in each of the five COGENT regions. One of the ICG site is located in Sikijang, Pekanbaru, Riau Province, Indonesia, which would cater to the Southeast and East Asia regions. The ICG is envisioned to:

1. Conserve the internationally, regionally and nationally identified coconut genetic resources diversity;
2. Further assess the identified diversity, evaluate the performance of the germplasm and distribute related information to COGENT member countries;
3. Make available germplasm materials to interested COGENT member countries in accordance with existing protocols; and
4. Conduct research and training to build up human resources capacity related to coconut genetic resources development.

So far, 29 coconut accessions from eight provinces in Indonesia have been established at the ICG-SEEA.

Strengthening the embryo culture capability for the ICG-SEEA

In terms of germination rate, embryos of different coconut varieties responded differently as well. The highest germination percentage was shown by the embryos of West African Tall (WAT), Polynesian Tall (PYT), Rennel Tall (RLT), Nias Yellow Dwarf (NYD), and Mapanget Tall (MPT) using the UPLB protocol. However, the highest seedling survival rates were recorded using the Philippines Coconut Authority (PCA) protocol.

Development of effective technology for the production of coconut seedlings from the soft- endosperm 'kopyor'

In March 2001, plant materials of Kopyor coconut were collected from the farmers' fields in Kalianda Region, Lampung Province. Forty seven seednuts were harvested and sent as whole nuts to ICOPRI in Manado, of which 40 embryos were found to be suitable for planting using culture medium. These embryos were planted in the culture medium using the upgraded embryo culture protocol. So far, eight seedlings produced are ready for field planting.

Importation and growing of designated germplasm from COGENT members countries for conservation in the ICG-SEEA

Activities undertaken included the preparation of chemicals, glassware, equipment and labour for embryo culture work. ICOPRI received 927 coconut embryos of Malayan Green Dwarf (MGD) and Malayan Tall in the form of cylindrical endosperm from MARDI on October 2002. The MGD embryos have been cultured with a 70% germination rate. So far, 95 plantlets have been conserved *in vitro*, 95 embryos failed to germinate while 84 embryos successfully germinated. On the other hand, 53 (73%) of the Malayan Tall embryos have germinated while 73 remained dormant. After hardening, these will be planted in the ICG-SEEA.

Farmer participatory research to identify varieties for multipurpose uses, and evaluation of germplasm for sap and sugar production

This COGENT project, funded by the International Fund for Agricultural Development (IFAD) aimed at identifying and conserving coconut genetic resources to increase the small-scale farmers' income and improve their nutrition. Three main activities have been implemented: (1) farmer participatory research to identify multipurpose uses of coconut and suitable varieties for those uses, and identify production constraints to enhancing farmer income; (2) promotion of smallholder production of sap from the hybrid PB 121 for sugar processing; and (3) evaluation of coconut germplasm collection in Mapanget. For sap and sugar production, farmer participatory research (FPR) was conducted in Lampung, Riau, Central Sulawesi and North Sulawesi. Within the four provinces surveyed, the local communities recognized 57 coconut accessions, consisting of 37 Talls, 12 Dwarfs and 8 hybrids. Some important opportunities identified include:

1. Potential diversified coconut-based high-value products;
2. Intercrops suitable for planting under coconut;
3. Genetic materials for coconut breeding and improvement programmes; and
4. Local sources for high-quality planting materials.

Forty-one farmers' varieties have been catalogued, 10 of which have good potential for breeding and/or direct distribution. Improved technology on sugar processing and packaging has also been developed in Lampung Province which could increase farmers' income by 4-5 times as compared with the traditional income from copra production. Performance evaluations of 12 varieties from Mapanget and Kima Atas Experimental Garden in North Sulawesi were conducted on sugar processing. Two accessions of the existing coconut germplasm evaluated exhibited high potential for producing sap and sugar. These varieties are the Nias Green Dwarf and Jombang Green Dwarf.

Poverty reduction in coconut growing communities

Based on socioeconomic surveys conducted among different coconut growing communities in Indonesia, three were chosen as sites for the implementation of an ADB-funded project on 'Poverty reduction in coconut growing communities'. The three pilot sites tested COGENT's 3-pronged strategy to reduce proverty, which includes:

- Increasing yields 3-5 times by introducing high-yielding and high-value coconut varieties;
- Increasing incomes 5-10 times by producing high-value products from the different parts of the coconut; and
- Increasing farm productivity 3-5 times through intercropping and livestock/fodder production.

This was undertaken in three villages, namely Wori and Nonapan villages in North Sulawesi Province and Huntu in Gorontalo Province, involving 748 farmers. Under the project, training was specifically geared towards empowering resource-poor farmers and socioecomically disadvantaged women, transforming them from being mere raw materials suppliers to village-level entrepreneurs. Under the project, a total of 7504 local and introduced Tall (Mapanget) varieties from ICOPRI have been planted on farm. For intercropping, the farmers planted corn, banana, peanut, stringbean, egg plants, cacao, jackfruit, cassava, and pineapple. They also produced poultry and livestock, especially swine and goats. Results of the project showed that farmers increased their incomes by 2-3 times through intercropping, livestock raising and producing high-value products from coconut such as coconut virgin oil and nata de coco.

Production of hybrids

Tall x Tall Hybrids

A number of selected local Mapanget Talls (MPT) such as MPT no. 2, MPT no 32, MPT no. 83 and MPT no. 99 have been crossed with each other to produce high-yielding hybrids, primarily for copra production. Some of these hybrids have been released in 1984 by the Ministry of Agriculture, which include KB-1 (32 x 32), KB-2 (32 x 2), KB-3 (32x83) and KB-4 (32 x 99). The other Tall x Tall hybrids produced were Tenga Tall (TGT) x Tenga Tall (TGT), Tenga Tall (TGT) x Bali Tall (BAT), Tenga Tall (TGT) x Palu Tall (PUT), Bali Tall (BAT) x Tenga Tall (TGT), Bali Tall (BAT) x Bali Tall (BAT) and Bali Tall (BAT) x Palu Tall (PUT).

Dwarf x Tall Hybrids

KHINA hybrids

In order to produce coconut hybrids with high productivity and precocity, the following crosses were made: Nias Yellow Dwarf (NYD) x Tenga Tall (TGT), Nias Yellow Dwarf (NYD) x Bali Tall (BAT), Nias Yellow Dwarf (NYD) x Palu Tall (PUT). These resulted in the KHINA hybrids, namely: KHINA-1, KHINA-2 and KHINA-3, which were released in 1984 by the Ministry of Agriculture for distribution to farmers.

New coconut hybrids

To find coconut hybrids with high yield performance, early bearing and require medium input, the following crosses were done: Raja Brown Dwarf (RBD) x Mapanget Tall (MPT), Nias Yellow Dwarf (NYD) x Takome Tall (TKT), Bali Yellow Dwarf (BYD) x Mapanget Tall (MPT) and Bali Yellow Dwarf (BYD) x Takome Tall (TKT).

Coconut hybrids suited to swampy areas

To find coconut hybrids with high yield performance, early bearing and especially suited to swampy area conditions, the following crosses were undertaken: Nias Yellow Dwarf (NYD) x Riau Tall (RUT), Tebing Tinggi Dwarf (TTD) x RUT, and Salak Dwarf (SKD).

Coconut hybrids resistant to bud rot

Observations are being done on 25 coconut hybrids to assess their resistance to the bud rot disease. Studies are still underway.

Looking ahead

A coconut breeding programme that would produce new varieties is the priority of ICOPRI. The main objective of the programme is to produce planting material on a large scale with desirable characteristics such as early fruiting and high copra yield. The other preferred characters by coconut farmers that will be incorporated into the genepool include: (1) tolerance to drought; (2) adapted to tidal swampy area; and (3) resistance to bud rot and nut fall diseases.

Southeast and East Asia

Status of coconut genetic resources research in Thailand

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Introduction

In Thailand, coconut plays an important role in the economy of the country and in the daily life of the Thai people. Farmers use coconut in various ways and maintain a wide range of varieties suited for different uses. Its cultivation is a major source of employment, income and food, especially for poor rural families. Owing to low income from traditional products such as mature nut, copra and coconut oil, diversification into alternative, high-value products is the country's major approach in helping increase farmers' incomes.

Research activities supported by COGENT

Technical assistance for a coconut genetic resources network in Asia and the Pacific Region (CGRNAP)

The technical assistance project was conducted from August 1994 to July 1997 whereby the participating countries of the International Coconut Genetic Resources Network (COGENT), including Thailand, had to identify and collect important accessions, especially those that are at risk to genetic erosion, and conserve these in their respective field genebanks.

For Thailand, a total of 34 ecotypes were collected and conserved in the national coconut genebank at Kanthuli, Thailand. Twenty existing accessions in Chumphon Horticulture Research Centre (CHRC) were also characterized and the data submitted to COGENT for inclusion in the Coconut Genetic Resources Database (CGRD).

Farmer participatory research on suitable varieties for multipurpose uses, particularly for sap and sugar production to enhance farmer incomes

In Thailand, coconut sugar is one of the most important ingredients in local dishes and cannot be replaced by other similar products as it renders a unique flavour. The purpose of this project was to refine the technology for producing coconut sugar by enhancing its quality through: (1) screening existing cultivars in farmers' fields to identify suitable varieties; and (2) evaluating Thailand's national germplasm collection for high-yielding sap for sugar production. The project had three components:

Component 1: Farmer participatory survey to identify production constraints, multipurpose uses and suitable varieties especially for sap and sugar production

A farmer participatory survey was conducted in Samut Songkhram and Samut Sakhon provinces where coconut sugar is mainly produced. Among the Tall coconut varieties identified as suitable for sap and sugar production were Thalaeba, Suricha and Saiboa, with an average yield about four to six litres of fresh sap/palm/day, whereas Krati and Kheekai variety produced three to four litres of sap/palm/day. These Tall varieties were preferred by farmers due to their high sap yield per spathe as well as for their strong leaf petiole to support tappers (sap collectors). Sawi Hybrid No. 1 was also identified as a good variety for sugar production because of its high number of spathe production and consistency of sap yield. The survey also showed that Dwarf varieties such as Aromatic and Green Dwarfs were also being grown for sap production.

Component 2: Improvement of technology for higher quality and production of coconut sugar and technology dissemination to farmers

This activity was carried out to: (1) refine the existing coconut sugar technology by improving the quality and production of granulated sugar through improved packaging; and (2) train farmers in the production and marketing of quality coconut sugar.

The study showed that with proper packaging, granulated coconut sugar could retain its ideal moisture content and appearance for up to 60 days. It was also found that coconut sugar has higher Vitamin A and sucrose content than sugar extracted from sugarcane. Under this component, two economy-size kilns for sugar making were built in the coconut farming communities of Village 5, Donyang Sub-district and Village 6, Pakkhlong Sub-district. Farmers from these two villages were successfully trained to produce and market quality coconut sugar.

Component 3: Evaluation of coconut germplasm accessions for sap and sugar production

Under this component, Thailand's national coconut germplasm accessions were evaluated for sap and sugar production. They were also characterized and the data submitted to COGENT's Coconut Genetic Resources Database (CGRD). Four coconut varieties (Thalaeba, CH60, SW.1 and Nakhon) were further evaluated and compared for sap yield.

The results showed that Nakhon Tall and the hybrid SW.1 were the better sap yielders of the four varieties studied.

Feasibility studies on coconut palm sugar and coconut shell handicrafts production and marketing

The studies were conducted from April to July 2000 by the Horticulture Research Institute which assessed the technical feasibility, financial and socioeconomic viability of producing and marketing coconut palm sugar and coconut shell handicrafts. The aim was to come up with recommendations for small- to medium-scale production modules for high-value products that will directly benefit coconut farmers.

Coconut palm sugar

Coconut sugar in Thailand is produced for both the local and export markets. Exports of the product have increased from 610 tonnes in 1995 to 1007 tonnes in 1999. Coconut sugar is exported to the United States, Australia, Japan, United Kingdom, France, Canada, Saudi Arabia, Germany, China (Hong Kong), Netherlands and Malaysia. Thus, increased palm sugar production helps in boosting national economy.

In Thailand, coconut sugar is made mainly by home industries in villages where coconut is grown. Coconut palms for sugar production are mainly planted in the provinces of Samut Songkram (Amphoe Ampawa, Bang kon tee, Muang), Samut Sakorn (Amphoe Ban paew), Rajchaburi (Amphoe Wat pleng, Pagtoh) and Petchaburi (Amphoe Ban Laem). The local varieties identified for coconut sugar include Moosri (yellow and green), Aromatic coconut (Nam Hom), Nam Wan, Thale Ba, Suricha, Saibuaw and Sawi Hybrid No.1. Coconut sugar production is a labour-intensive industry with more than 54% of total cost attributed to labour cost. According to field surveys conducted in Ratchburi and Petchburi Provinces, it was found that the average gross income of a coconut sugar farmer is about 25 071 baht/ha/year (US$ 604), with net profit of 28% of gross sales. Based on the findings of this study, farmers were encouraged to: (1) sell their product directly to the markets to cut out the cost of intermediaries; (2) build a kiln to reduce labour costs; and (3) plant suitable varieties that produce more sap or syrup.

Coconut shell handicraft

Coconut shell handicrafts such as necklaces, bracelets, bags, belts, ladles, buttons, etc. are produced for both domestic and export markets. In 1999, income from coconut shell handicraft production amounted to more than 45 million baht (US$ 1.1M). The main production areas of coconut shell handicrafts are in Phattalung, Songkhla, Chumphon and Surat-thani.

Coconut shells for handicraft-making should be thick, round or globular in shape. Among the suitable varieties for coconut shell handicraft-making are Sawi Hybrid No.1, Thai Tall and West African Tall.

The feasibility study on the production and marketing of coconut shell handicrafts carried out by the Khog Wuaw Group in Phattalung, Thailand revealed that there was an increasing demand for coconut shell handicraft especially in the international market. Coconut shell handicrafts production had also contributed to the creation of more employment opportunities for the people in rural areas and helped increase their incomes, resulting to improved living standards in the community (Naka 2000).

Establishing a framework and selecting project sites for a nation-wide deployment of coconut-based poverty reduction interventions in coconut growing communities

In 2001, surveys were conducted in coconut-growing regions of the country to select project sites for deployment of coconut-based poverty reduction interventions in coconut-growing communities using COGENT's 3-pronged strategy, which are: (1) to increase yields and incomes by deploying high-yielding, high-value multi-purpose and adapted coconut varieties and using locally produced seednuts and embryo culture-derived seedlings; (2) to promote the production and marketing of high-value coconut products from all parts of the coconut and identify suitable varieties for these; and (3) to enhance food security and nutrition through intercropping and livestock/fodder production in a coconut-based farming system.

The site evaluators were required to ensure that the selected pilot communities were poor but had the potential for poverty reduction interventions. The pilot sites should preferably be characterized by low economic development, extreme isolation and a very fragile ecology with saline to brackish water, low soil nitrogen content, extreme agroclimatic conditions and where coconuts were one of the main agricultural crops grown.

Based on the criteria above, five communities were selected, namely: (1) Ban Khog Wuaw coconut shell handicrafts production community, Amphoe Muang, Phattalung Province; (2) Sang-Aron and Tapsakae coconut farming community, Amphoe Taksakae, Prachab-kirikhan Province; (3) Ban Chong Zai coconut shell handicrafts community, Amphoe Muang, Chumphon Province; (4) Bangkrog coconut sugar community, Amphoe Banleam, Petchaburi Province; and (5) Ban Kao Roup Chang coconut shell handicrafts community, Amphoe Sadao, Songkhla Province.

Enhancing incomes and reducing poverty in coconut growing communities in Thailand

The main purpose of the project is to identify high-value products which could generate income for resource-poor rural farmers and socioeconomically disadvantaged women. Based on the technical, financial, management and socioeconomic studies conducted under the project, the five selected coconut communities in Thailand (Ban Khog Wuaw Community, Sang-Aron Tapsakae Community, Ban Chong Zai Community, Bangkrog Community and Ban Kao Roup Chang Community) would serve as strategic model sites for training cum demonstration of coconut-based income generating strategies for the regional service area. The work was completed on 31 December 2000. Three of these communities (Sang Arun Community in Prachab, Ban Chong Zai Community in Chumphon and Ban Khog Community in Phattalung) will be supported in the IFAD-funded poverty reduction project of COGENT (2005-2008).

Application of COGENT's upgraded coconut embryo culture protocol using three Thai coconut varieties

This project was carried out in June 2001 to undertake coconut embryo culture and acclimatization research for three Thai coconut varieties; and to further test the use of the upgraded coconut embryo culture protocol. Under this project, Mr Somdej Woralakphakdee, a Thai agronomist and coconut breeder, was trained on the use of the upgraded protocol at the Albay Research Centre, the Philippines from 9 to 16 October 2000. Mr Somdej has further experienced the use of the upgraded coconut embryo culture protocol to validate three Thai coconut varieties (Thai Tall-Maphrao Yai, Thung Khled Dwarf and Chumphon hybrid No. 2). Upon his return, he used skills gained to do embryo culture research using local varieties.

Collecting, characterizing and conserving young tender coconut ecotypes

A survey was conducted in 10 young tender coconut growing provinces with the aim of collecting germplasm with diversified characteristics. During the survey, it was found that two groups of the Green Dwarfs, Aromatic coconut (Nam Hom) and Sweet water coconut (Nam Wan), were widely grown on a commercial scale. However, other Dwarfs, such as the Yellow, Red and Brown Dwarfs, were also found growing in home gardens for drinking purpose. These varieties are considered rare and endangered. A palm of the Nam Wan variety, characterized by a pink mesocarp, was also found to be a rare variety. A total of 14 local Dwarf accessions were collected and planted in the field at Chumphon Horticulture Research Centre (CHRC).

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Southeast and East Asia

Status of coconut genetic resources research in Vietnam

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Introduction

Coconut (*Cocos nucifera* L.) is considered the most important perennial oil crop in Vietnam, with an estimated total cultivated land area of 250 000 ha. In Vietnam, the coconut and its by-products is the main source of income for thousands of farmers and their families, especially in rural areas. The crop is pivotal in the government's national poverty reduction programme and is considered as a strategic oil crop that has the potential of earning much needed foreign exchange.

An average coconut holding in Vietnam is relatively small, about 0.2 – 0.3 ha. Coconut yields, as well as nut prices, are also quite low. Most palms are currently affected by the coconut leaf beetle (*Brontispa longissima* Gestro), resulting in low yields. Although a variety of high-value products are being produced, marketing channels are not well-organized. Most coconut farmers produce mostly whole nuts and copra and are suffering due to low price of these traditional coconut products. Recently, the price of coconut has been better because of the increased local demand (most of which is then processed and exported) but even this price level is unstable. High income generating technologies for producing high-value products from the other parts of the coconut are not readily available for all coconut growing communities. Another major problem facing coconut producers and processors is the lack of access to capital for investing in more modern and efficient coconut cultivation and processing technologies.

On the other hand, Vietnam has a wide coconut genetic diversity base with potential varieties for specific uses such as the Ta, Dau and Bung Talls for oil production and making products by processing husk, shell and water; and the Xiem and Tam Quan Dwarfs for tendernut (drinking) production. High-value coconut varieties such as Sap (Makapuno), Dua (Aromatic) also offer potential high-income alternatives for coconut farmers.

Vietnamese farmers have extensive knowledge of and experience in coconut cultivation under different agroecological conditions, especially in the Mekong Delta. Most of them are organized into community-based organizations (CBOs), which make the technology transfer of advanced coconut-based farming system (CBFS) models and new high-income generating, coconut-based techniques easier. Vietnamese farmers are also very adept in producing high-value coconut fibre-based, shell-based and wood-based products at the household and village levels.

Funds for coconut R&D activities are provided by the Vietnamese Government annually. Coconut extension activities are also funded by the central government as well as by the local or provincial government units. International donor funding support for projects in Vietnam is very important to help strengthen coconut research activities in the country. Up to now, most funds from international donors like the Asian Development Bank (ADB), the International Fund for Agricultural Development (IFAD), and the Department for International Development (DFID) have been provided through projects coordinated by the International Plant Genetic Resources Institute's International Coconut Genetic Resources Network (IPGRI-COGENT). Due to the vital role that coconut plays in rural Vietnam, the Oil Plant Institute of Vietnam (OPI), the government organization mandated to lead the development of the coconut industry in the country, has been strongly supported by the central and provincial governments as well as international organizations like the Food and Agriculture Organization (FAO) to carry out various coconut R&D programmes. Priority activities that OPI focuses on include: breeding, germplasm conservation and management, improved cultivation techniques and coconut-based farming system (CBFS), crop protection and diversification of coconut-based products for sustainable livelihoods and development.

Research activities conducted and outputs

Coconut germplasm collection and conservation

Forty-five coconut accessions have been conserved in the field genebank in Dong Go Experiment Station following the guidelines provided by IPGRI-COGENT. They include 11 exotic and 34 local accessions. Of these, six are predominantly for oil and copra production adapted to alluvial soils of the Mekong Delta; three for oil and copra production and tolerant to the acid sulfate soil of the Mekong Delta; six for oil and copra production in the sandy soil of the Central Vietnam's coastline; six for oil and copra production in the highlands and mountain areas of Central Vietnam; four for oil and copra production in the industrial zones; one for oil and copra production in the island area; four for drinking (tendernut) for the Mekong Delta; and four rare and precious accessions. In addition to *ex situ* conservation, *in situ* (on-farm) conservation has also been applied to rare accessions.

Coconut embryo culture technique has been applied using COGENT's upgraded protocol for germplasm exchange and multiplication of the true Makapuno nuts. Three local varieties: Eo Dwarf, Dua (Aromatic) and Sap (Makapuno) were tested, showing that the protocol was suitable for embryo culture of local coconut varieties. However, field planting of the embryo culture-derived coconut plantlets has not been very successful.

Coconut germplasm characterization, evaluation and use

Passport and characterization data on all coconut accessions planted in the field genebank have been collected and submitted to the International Coconut Genetic Resources Database (CGRD). Some of these germplasm have been successfully used for producing high-yielding coconut hybrids such as PB121, PB141, JVA1 and JVA2. Out of these four hybrids produced by OPI, PB121, JVA1 and JVA 2 were recognized and approved by the Vietnamese Government for large-scale dissemination to farmers under its national coconut project.

Multipurpose uses of coconut germplasm and diversification of coconut-based products

Through ADB and IFAD-funded projects, the identification of suitable coconut varieties for different purposes based on the market studies and social research was conducted. Results showed that there were two main purpose-specific uses of coconut in Vietnam: (1) oil extraction and by-product processing; and (2) tendernut production (drinking). Suitable coconut varieties for specific purposes or uses have been recommended to farmers as a result of the germplasm characterization and evaluation activities. The market survey of coconut-based products targeted three main groups: consumers, enterprises and producers/sellers. The study identified a close relationship among these market players. It also identified the most marketable and acceptable high-value coconut products derived from all parts of the coconut that can be produced by the households and villages (products from coconut fibre such as doormat, snowmat, geotextile, etc.; products from coconut wood such as handicrafts; products from coconut shell such as handicrafts, shell charcoal; products from coconut midribs such as basket, products from coconut meat such as coconut candy, coconut paper etc.). OPI has also helped in this area by recommending and disseminating to farmers coconut varieties that are suitable for these identified products or use such as the Xiem, Dua and Tam Quan (for drinking and for ecotourism), and the Ta and Dau varieties (for oil production and by-product processing listed above) as well as ecotypes and hybrids.

Meetings/ workshops

From 1999 to 2004, Vietnam has hosted five important COGENT-sponsored meetings, including the annual meetings for the ADB and IFAD-funded projects, the 8^{th} COGENT Steering Committee meeting in September 1999, the project inception and stakeholders' meeting of the ADB-funded 'Poverty Reduction in Coconut Growing Communities Project' in February – March 2002 and the final ADB-funded project meeting on Poverty Reduction in Coconut Growing Communities (PRCGC) in September 2004. All these meetings were held in Ho Chi Minh City and hosted by OPI.

Training and human resources development

From 1997 to 2004, four local OPI staff members were sponsored by COGENT for capacity-building training in other countries on topics such as coconut collecting and conservation, technical/proposal writing and seminar presentation, coconut data analysis, embryo culture techniques, standardized research techniques in coconut breeding (STANTECH), and poverty reduction strategies in coconut growing communities. Two project staff members were also given MSc and PhD scholarships related to plant genetic resources (PGR). In 2001, six sets of Vietnamese- designed coconut processing machineries were transferred to Bangladesh, the Philippines, Indonesia, PNG with the help of consultants and to Kenya and Malaysia. In 2003, one COGENT-sponsored training course was conducted in Vietnam on 'Communication, Documentation, Public Awareness and Facilitation Skills Development', which was held from March 13-15 at OPI's Headquarters in Ho Chi Minh City wherein 20 officers and staff from OPI and the Ministry of Agriculture and Rural Development (MARD) participated. Vietnam staff also conducted training on coconut candy making in Malaysia, Indonesia, the Philippines, Fiji, PNG and Bangladesh.

Publications, scientific papers and public awareness materials produced

Over the past years, a variety of papers and documents relating to coconut genetic resources R&D and results of IPGRI-COGENT projects in Vietnam have been compiled, published and widely disseminated for use in training, public awareness and extension activities. These include posters, brochures, handouts, books, video tapes, catalogues, manuals and newspaper articles. The most notable include:

- Science report and catalogue of conserved coconut germplasm in Vietnam;
- Catalogue of farmers' coconut varieties in Vietnam;

- Manual and video on the production of high-value coconut fibre-based products;
- Manual and video on the production of high-value coconut wood-based products;
- Manual on the production of coconut-based candy and other confectionaries;
- Catalogue of Vietnamese coconut food recipes;
- Brochures on recommended high-yielding and high-value coconut varieties, models of intercropping and livestock production and diversified coconut products from the meat, fibre, shell, wood and leaves;
- Brochure on *Brontispa longessima* Gestro control on coconut;
- Manual on the techniques for coconut selection, nursery management and assisted pollination;
- Two videos on coconut production and processing; and
- Video documentation of the activities of the community-based organizations (CBOs) participating in the ADB-funded PRCGC project.

Assistance to Vietnam's coconut genetic resources' thrusts

From 1994 to 2000, five COGENT specialists visited Vietnam on five technical assistance missions to:

- Assess the country's coconut R&D capability and to assist the national programmes in identifying common problems and opportunities for network collaboration;
- Identify marketable alternative coconut products and suitable coconut varieties;
- Evaluate Vietnam's coconut germplasm using COGENT's collecting and conservation strategies;
- Assist in setting up a laboratory and embryo culture experiments;
- Conduct studies to identify strategies and interventions to enhance farmers' incomes and reduce poverty in the coconut growing communities of the country;
- Conduct training on technical writing, seminar presentation and public awareness; and
- Conduct marketing survey on coconut high-value products.

In addition, COGENT also assisted Vietnam in preparing project proposals and identified donors, including foreign embassies and international organizations in Ha Noi, to replicate COGENT's poverty reduction project in the country.

Interpretation of significance or impact of outputs

The biggest impact of the COGENT projects' outputs is that farmers now believe in their coconut crop. They can get income higher than before by doing many activities such as selecting and planting high yielding and high-value coconut varieties (HV), intercropping, livestock production (with biogas production), HV products from meat, fiber, shell, midribs, as well as conserving their indigenous coconut germplasm for long term use. The results were that income of coconut farmers in the project sites increased 2-3 times (in some cases even by 4 times).

Government authorities, including departments of agricultures & rural development, department of industry, trade and tourism, associations of women and farmers, economic and social affairs, etc. really paid attention with high appreciation to the COGENT – funded projects' in Vietnam. Actually, coconut is now classified as a commodity that have comparative advantage to the country due to its significant contribution to the economy, society and environment.

COGENT-funded project sites really became demonstration sites for generating incomes from coconut and proved that coconut farmers need not be poor even with limited resources if they applied COGENT's 3-pronged strategy on poverty reduction combined with their diligent working and support from the community. Many foreign delegations from Mexico, Malaysia, Ivory Coast, Kenya, PNG, the Philippines, etc. and from international donors such as Inter-American Development Bank (IADB) also visited and studied Vietnam's experiences on coconut R&D.

Positive change in the way coconut is viewed in Vietnam from the agricultural and industry sectors' perspectives

The 'picture' of coconut in the country has changed considerably. Due to continuous efforts and gains in coconut R&D through the different initiatives of OPI and its partners, many people now consider coconut as the 'tree of prosperity' because of the stable and increased incomes derived from coconut production and processing activities. As a result, the government has implemented measures to retain and even increase the area devoted to coconut, thereby preserving precious coconut germplasm that are otherwise in danger of genetic erosion (i.e., farmers have previously cut down their coconut trees to give way to more valuable fruit trees). In industries, demand for high-value products such as desiccated coconut and activated shell charcoal, among others, in both local and international markets has been so high that factories for these products, particularly in Ben Tre and Tra Vinh Provinces (the first and second largest coconut growing provinces in the country), have been experiencing a shortage in coconut raw materials. In fact, two coconut factories in Ben Tre Province alone use about 100 million coconuts per year to sustain production levels! More factories are planned to be established in other provinces, although the same raw material shortfall scenario is expected.

Social, economic and psychological impact on coconut farmers

As support for coconut is increasing in the country and the crop's relevance to alleviating poverty in the rural areas is becoming more evident, coconut farmers are now more and more convinced that coconut is indeed the 'tree of life and prosperity'. For them, coconut can provide stable incomes throughout the year as compared to other fruit crops. Hence, they do not want to cut down palms anymore as they previously did when coconut prices and support were down. They are planting more coconuts because they are now more aware of the crop's economic, social and ecological importance. Coconut farmers now understand that they need not be poor as there is great potential for diversification of coconut-based products which could give them more income and other non-monetary benefits. In some areas of the country, particularly in the Mekong Delta, the coconut tree is indispensable as it contributes significantly to viable multi-cropping systems, especially those involving shade-loving food security and cash crops.

Overall improvement of Vietnam's coconut industry

Advancements in coconut R&D in the country, particularly on production and processing, have translated to significant improvements in Vietnam's coconut industry. For example, VOCARIMEX, a state company producing and trading in vegetable oils, has substituted 60% of its total vegetable oil production with coconut oil. In addition, coconut has increasingly contributed to the nation's foreign exchange earnings from exports of high-value coconut products to markets in Asia, Europe and the United States. Ironically, this has led to problems in raw materials supply, pushing the prices of coconuts up, which, in retrospect, is good for coconut farmers as they now earn more from their crop.

Enhanced internal capacity (infrastructure and human resources) of OPI

Through R&D activities and projects on coconut genetic resources as supported by the national government and IPGRI-COGENT, human resource capacity of OPI has considerably been improved through training and post-graduate (MSc and PhD) degree programmes. This has helped a lot in keeping coconut genetic resources-related activities in Vietnam at par with neighbouring coconut growing countries. Likewise, research facilities have also been upgraded consistent with the staff capacity level. These have been decisive factors for the success of projects undertaken by OPI in collaboration with its partners since 1994 and up to the present.

Contribution to global coconut research

Through IPGRI-COGENT, Vietnam has transferred coconut-based processing technologies to other countries in the form of equipment, machinery, publications and training. Vietnam has so far exported locally-designed coconut fibre processing equipment and technologies to six countries (Bangladesh, Indonesia, the Philippines, Papua New Guinea, Malaysia and Kenya). Mexico is currently negotiating for one set of this equipment for replication and distribution to its coconut farmers. Manuals on the production of coconut fibre- and wood-based high-value products as well as on coconut candy-making from the kernel have been provided to COGENT for use in related training in the network's 38 member countries, particularly for coconut-based poverty alleviation interventions in poor coconut growing communities.

Bilateral and multilateral cooperation have also been strengthened. Projects have been initiated and/or completed between Vietnam and other countries and international organizations such as the Australian Centre for International Agricultural Research (ACIAR) on coconut embryo culture for germplasm exchange, the FAO on coconut Brontispa control, the FAO regional project on wet – processing coconut oil (involving Thailand, Vietnam and Myanmar), with Instituto Nacional de Investigaciones Forestales Agricolas y Pecuarias (INIFAP) of Mexico.

Suggested next steps

To sustain the gains achieved in coconut genetic resources R&D and its applications in Vietnam, the following future endeavours are suggested:

1. Continue the support from international organizations for coconut research and development activities in Vietnam. This would help the country effectively maximize the available potential of coconut, help improve the plight of poor coconut farmers and enhance the sustainable development of coconut in particular and Vietnam's agricultural sector in general;
2. Continue the support for human resource capacity development (long term and short term) in coconut R&D. This also includes experience sharing and technology exchange particularly on coconut production and processing among coconut producing countries of COGENT;
3. Conduct more intensive and specialized coconut research activities (e.g. molecular marker, chemical research on food and non-

food coconut-based products, product diversification, etc);
4. Continue the support for maintaining and evaluating the available coconut germplasm in the existing genebanks as well as for exploring and collecting more precious and rare coconut varieties to complement the national coconut collection; and
5. Augmenting Vietnam's coconut genetic resources through importation of desirable varieties for breeding from COGENT member countries.

Southeast and East Asia

Status of coconut genetic resources research in Malaysia

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Introduction

In Malaysia, coconut ranks the fourth most important crop in terms of area planted, after oil palm, rubber and rice, respectively. In 1981, the total area planted to coconut was 409 348 hectares, but in 1995 it drastically declined to 248 380 hectares, which represent about 5% of the country's total agricultural land area. As in the rest of the countries in the Asia and Pacific region, smallholders, with an average farm size of 2.8 ha, dominate coconut production in the country, producing about 93% of the total coconuts in the country. It is estimated that a total of 90 000 farm families are involved in coconut production.

The local demand for the crop is mainly in the form of fresh nuts, coconut oil and processed products such as desiccated coconut and coconut cream. Despite the shrinkage of the area under coconut, the country is still a net exporter of coconut products. In 1995, exports were valued at about RM 165.2 million (US$ 43.5 million), primarily in the form of coconut oil, desiccated coconut, copra and fresh whole nuts. Imports of coconut and related products, on the other hand, amounted to RM 77 million (US$ 20.3 million). However, over the years, the international prices of copra dropped, which resulted in a corresponding decrease in coconut cultivation and production. The competition for land for oil palm planting and infrastructure development also significantly contributed to the reduction of coconut hectarage in the country. All of these factors have, therefore, endangered the coconut genetic resources of the country.

To mitigate this situation, the Malaysian Government, primarily through the Malaysian Agricultural Research and Development Institute (MARDI), collaborated with a number of international coconut R&D organizations, particularly International Plant Genetic Resources Institute/International Coconut Genetic Resources Network (IPGRI/

COGENT), to undertake research and development activities aimed at improving the country's coconut genetic resources.

COGENT-coordinated research activities conducted and results/outputs produced

Further collecting and *ex situ* conservation of coconut germplasm and characterization of existing germplasm collection

The main purposes of this collaborative activity were to: (1) train personnel on collecting and characterization procedures according to the Standardized Research Techniques in Coconut Breeding (STANTECH) manual; (2) collect and conserve coconut germplasm in the states of Kelantan and Terengganu; (3) collect and conserve coconut ecotypes from drought areas in the state of Sabah; (4) characterize existing coconut germplasm collection at MARDI-Hilir Perak Station and in the Department of Agriculture (DOA)-Sabah; and (5) submit passport and characterization data at the International Coconut Genetic Resources Database (CGRD).

A research officer from DOA-Sabah was trained in the collecting and characterization procedures for coconut germplasm based on the STANTECH Manual in Los Baños, Laguna, Philippines from 30 August to 10 September 1999. Seednuts of less known ecotypes, namely 'kelapa ringan', 'kelapa hijau', sweethusk and spicata were collected in Kelantan and Terengganu States and sown in MARDI's Research Station in Jerangau. Seven ecotypes of drought-tolerant Tall cultivars were collected from Sabah, the seednuts of which were sown in polybags at the nursery in Ulu Dusun Agriculture Research Station. Characterization data of 26 accessions from MARDI- Hilir Perak and 47 accessions from DOA-Sabah have been submitted to the COGENT's CGRD.

Sustainable use of coconut genetic resources to enhance incomes and nutrition of coconut smallholders in the Asia-Pacific region

The project aimed to: (1) identify multipurpose uses of the coconut in households, farms and domestic markets; (2) identify the varietal preferences of coconut farmers; (3) identify coconut production constraints; (4) undertake intercropping technologies and trials; (5) conduct a market survey of coconut-based products; (6) conduct a profitability analysis of different coconut-based intercropping models; and (7) transfer improved technologies to farmers.

Kelapa hijau (green coconut), kelapa dadeh (same as Makapuno), kelapa rambai (spicata), kelapa sabut manis (sweet-husked coconut) and kelapa besar (big coconut) were identified as the preferred varieties of farmers. It was also found out in the survey that the oil produced from the green coconut has medicinal properties. The main constraints to coconut production were senile coconut palms, low prices of coconut and lack of workers in the farm. To address this, it was recommended that a comprehensive replanting programme be implemented to replace the old palms with high-yielding varieties and hybrids, and request the government to peg the farmgate price for coconut. From the profitability analysis and market survey, it was determined that banana, lime and pineapple, in that order, are the best intercrops for coconuts. The technologies generated from this project have been disseminated to coconut farmers.

Deployment of coconut-based poverty reduction interventions in coconut growing communities

In 2001, surveys were conducted nationwide to select project sites for a nationwide deployment of coconut-based poverty reduction interventions in coconut-growing communities using COGENT's 3-pronged strategy of:

1. Increasing yield and incomes through the deployment of high-yielding, high-value multi-purpose and adapted coconut varieties, and using locally-produced seednuts and embryo cultured seedlings produced locally and internationally;
2. Promoting the production and marketing of high-value coconut products from the meat, husk, shell, water, wood and leaves and identifying suitable varieties for these uses; and
3. Enhancing food security and nutrition through intercropping and livestock/fodder production.

The evaluation was carried out to ensure that the selected coconut-producing communities were indeed poor but have the potential for poverty reduction. The identified sites are economically underdeveloped, isolated and ecologically fragile. The communities have saline and brackish water, low nitrogen soil, high average temperature and prone to typhoons. On the other hand, the coconut farmers interviewed in these sites have shown much interest in the project and the interventions to be introduced, particularly on the processing of coconuts into high-value products. Based on the survey, eight communities were selected as pilot project sites: Hutan Melintang, Telok Baru, Rungkup, and Bagan Datoh in Perak; Kampung Baru and Kampung Tengah, in Selangor; and Sikuati and Matunggung in Kudat, Sabah.

Validation of the COGENT-upgraded coconut embryo culture hybrid protocol

Training and research grants were provided to five countries (Bangladesh, Malaysia, Vietnam, Thailand and the Philippines) to test and refine, under local conditions, COGENT's upgraded coconut embryo culture protocol which was previously developed through the Department for International Development (DFID) funding by combining the good qualities of three protocols (developed in the University of the Philippines at Los Baños and the Philippine Coconut Authority's Albay Research Centre, Philippines, and the Central Plantation Crops Research Institute, India). The three local Malaysian coconut cultivars tested were supplied by the Department of Agriculture (DOA) Sabah, namely Malayan Red Dwarf (MRD), Malayan Yellow Dwarf (MYD) and Sabah Local Tall (SBT).

The research revealed that the germination rates of the embryos were low for all the test cultivars. Non-germinating embryos were highest for MRD (43.3%), followed by SBT (22%) and MYD (19.3%). Contamination was high in all of the cultures and this problem needs to be addressed. The plantlets that survived were transferred to polybags and sent to the greenhouse. To date, the average survival rate in the greenhouse is about 12%. This high mortality rate in the greenhouse was due to inexperienced handling of the acclimatization of coconut plantlets as this was the first attempt to do such work.

Farmer participatory research on farmers' varieties and multipurpose uses of coconut, and evaluation of improved intercropping models

Farmer participatory research to identify multipurpose uses of coconut and suitable varieties for these uses to enhance farmers' income

Farmer Participatory Research was conducted to identify multiple uses, varieties planted and production constraints of the coconut community in Sabah. The identified coconut farmers' varieties were documented and a catalogue containing 60 coconut recipes was compiled to give general information on how the use of coconut can be maximized.

Evaluating coconut-based intercropping technology models as potential strategies for increasing farmers' income and promoting germplasm conservation in coconut farms

An intercropping trial was established at Kg. Kumbatang Kudat with the aim of increasing farm income and promoting *in situ* germplasm conservation. Crops such as pineapple, vegetables, fruits, maize and banana performed well as intercrops in a coconut-based farming system.

The experimental plot established at Sikuati also served as a demonstration plot.

Future activities

Maintenance and evaluation of coconut germplasm. The existing conserved population will be evaluated and propagated as planting materials. Besides evaluating for their yields, traits or characters for specific purposes will be assessed.

Maintenance and dissemination of the results. Dissemination of the research results to the farming community will be intensified through training and setting up of demonstration plot in the State of Sabah.

Improvement of coconut-based farming system. Integrated farming system is one of the recommended strategies to improve the economic status of the farmers. The economic feasibility of such integrated system should be studied further. High- value crops should be identified and a marketing system for the farm produce should be developed.

Southeast and East Asia
Status of coconut genetic resources research in the Philippines

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Introduction

The Philippines has a total land area of 300 000 sq km, stretching 1839 kilometres from north to south, and is located off the southeast coast of Asia. Its 7107 islands make the Philippines one of the largest island groups in the world.

The Philippine coconut industry for so many years now has been heavily dependent on the production of traditional products mainly copra, coconut oil and copra cake. In fact, 90% of the total production goes to copra and coconut oil, which comes from only 35% of the whole nut. The other 65% - the husk, water, and shell - are underutilized. Processing procedures have been stagnant for decades and presently the Philippine coconut industry is losing market ground to other vegetable oils. Unless this trend is reversed, the Philippine coconut industry would certainly be doomed. While major headways have been attained in the area of agricultural research and development (R&D) especially on increasing production through varietal improvement, integrated coconut-based farming systems and integrated pest control, research efforts to focus on new sources of income from product diversification, improved product quality and new technologies to enhance the competitiveness of the industry have been more of an academic exercise. As such, these achievements in coconut R&D have not contributed meaningfully in strengthening the market position of the industry, thus seriously putting the industry's growth and development in a precarious situation.

The Philippine's coconut area is estimated at 4.09 million hectares, with most areas comprised of small landholdings with an average farm size of 3.6 ha. However, 72% of these landholdings are below 3.0 ha (Batugal and Oliver 2003).

Coconut genetic resources in the Philippines

Currently, the Philippines has 224 coconut accessions listed in the International Coconut Genetic Resources Database (CGRD) of the International Coconut Genetic Resources Network (COGENT). The Research, Development and Extension Branch of the Philippine Coconut Authority (RDEB-PCA) reported that there are 16 coconut varieties registered with the Philippine National Seed Industry Council (NSIC), while there are 15 registered coconut hybrids.

The national coconut yield level is 39 nuts/tree per year or 0.781 t of copra/ha per year (Table 1). Meanwhile, PCA's Zamboanga Research Centre (PCA-ZRC), in it's RDEB Annual Report 2000, reported that tall coconut populations attained copra yields ranging from 4.93 –13.68 t/ha, with Salambuyan (SALT), Aguinaldo (AGDT), Baybay (BAYT) and Gatusan (GATT) eclipsing the 10-tonne mark. Dwarf coconut population achieved copra yields ranging from 5.58 – 13.78 t/ha with 10 Dwarf accessions exceeding the 10 t mark. For the PCA-recommended hybrid varieties, annual copra yield per hectare reached between 4.0-6.0 t. Average nut production per tree per year in the farmers' field is 52.

Table 1. Coconut area, number of bearing trees and total nuts gathered by region, Philippines (CY 1999 - 2000)
(Source: Batugal and Oliver 2003)

REGION	Coconut area (in '000 ha)		No. of bearing palms (in '000)		Total nuts harvested (in '000 000)	
	1999	2000	1999	2000	1999	2000
CAR	0.23	0.23	48.00	48.00	0.73	0.68
Ilocos Region	10.58	10.72	2276.00	2284.00	17.81	19.02
Cagayan Valley	7.72	9.72	1333.00	1343.00	37.69	47.95
Central Luzon	3.13	3.45	177.00	218.00	5.59	5.51
Southern Tagalog	734.13	746.93	59 149.00	59 074.00	1999.25	1955.12
Bicol	667.08	655.49	28 233.00	28 233.00	1124.11	1146.84
Western Visayas	123.80	123.49	10 114.00	9678.00	342.57	400.87
Central Visayas	156.24	156.16	12 638.00	12 565.00	304.25	298.96
Eastern Visayas	618.88	619.02	53 793.00	53 793.00	1551.01	1544.81
Western Mindanao	404.18	402.86	35 024.00	35 267.00	1331.85	1378.14
Northern Mindanao	231.92	231.92	14 820.00	17 677.00	546.77	564.83
Southern Mindanao	491.12	491.11	43 857.00	43 857.00	3338.76	3323.44
Central Mindanao	118.34	118.34	11 416.00	11 416.00	425.03	419.70
CARAGA	265.21	261.88	16 417.00	16 354.00	519.67	491.86
ARMM	258.60	258.80	26 319.00	26 319.00	958.90	901.38
TOTAL	**4091.16**	**4090.12**	**315 614.00**	**318 126.00**	**12 503.99**	**12 499.11**

PCA's genebank in Zamboanga is considered to be one of the most important germplasm repositories of local and foreign coconut ecotypes in the world, where 224 coconut accessions are being maintained. Eleven accessions are of foreign origin, such as the West African Tall (WAT), Rennel Island Tall (RIT), Gazelle Peninsula Tall (GPT), Markham Valley Tall (MVT), Vanuatu Tall (VTT), Karkar Tall (KKT), Malayan Red Dwarf (MRD), Malayan Yellow Dwarf (MYD), Equatorial Guinea Green Dwarf (EGD), Sri Lanka Green Dwarf (SGD) and Aromatic Green Dwarf (AROD). The introduced materials make it possible for the country to participate in the planned global coconut-breeding programme of COGENT.

Like other countries, Tall varieties dominate the areas planted to coconut. The major Tall populations grown in the country are Laguna (LAGT), Bago-Oshiro (BAOT), Baybay (BAYT), Makapuno (GUZT), San Ramon (SNRT), Tagnanan (TAGT) and Hijo Tall (HJT). The Dwarf varieties include Catigan (CATD), Tacunan (TACD), Kinabalan (KIND) and Aromatic (AROD).

Apart from the 11 introduced accessions, 22 are hybrid/line collections. The first three locally-produced hybrids, namely PCA 15-1 (CATD x LAGT), PCA 15-2 (MRD x TAGT) and PCA 15-3 (MRD x BAYT), were mass-produced using the assisted pollination breeding technique for the planting/replanting programme of the PCA. Other hybrids produced which were also registered with the National Seed Industry Council (NSIC) are PCA 15-4 (CATD x TAGT), PCA 15-5 (CATD x BAOT), PCA 15-6 (CATD x PYT), PCA 15-7 (MRD x PYT), PCA 15-8 (TACD x BAOT), PCA 15-9 (TACD x TAGT), PCA 15-10 (TACD x LAGT), PCA 15-11 (TACD x WAT), PCA 15-12 TACD x RIT), PCA 15-13 (MRD x LAGT), PCA 15-14 (MRD x BAOT) and PCA 15- 15 (CATD x BAYT). These hybrids were selected based on their outstanding and stable yield performance as well as economic profitability (Santos *et al.* 2000). Registered local Dwarf and Tall varieties are CATD, TACD, BAYT, TAGT and BAOT. The local Tall Baybay is recommended as planting material while promising varieties like TACD, CATD, AROD, MRD, RIT and Baybay are used for seednuts propagation.

In an attempt to try new breeding methods to produce an open-pollinated variety (OPV), the PCA is introducing the Syn Var 001, nicknamed 'GMA Coconut Variety', or technically known as Genetically Multi-ancestored Farmers Coconut Variety, which is considered as the hybrid of hybrids. The base populations are the F_1 hybrids originating from six Tall populations, which were found to possess good general combining ability. GMA is an open or cross-pollinating population of highly heterozygous individual palms. Farmers can use the succeeding seed generation for subsequent planting and this will make the coconut farmers more self-reliant in the production of their own hybrid seednuts.

Recently, two Philippine Dwarf varieties, Galas Green Dwarf (GALD) and Tacunan Green Dwarf (TACD) passed the international standards set by the C&A Products Co., Ltd. of Thailand for young tender coconut. These were found to be better than the famous Thai aromatic varieties Nam Hom (HOM) and Nam Wan (WAN). A recent addition to the PCA genebank is a rare coconut called 'Tutupaen' or 'Tupa', whose shell is so thick that it's almost as thick as its meat. Nuts from the 'Tutupaen' are not consumed due to superstitious belief that once eaten, the shell will become brittle. Debris from the 'Tupa' tree is also buried for the same reason (Calub 2002). 'Tutupaen' nuts are used solely for 'Tupa', a local throw-and-hit game wherein the players involved try to hit the opponent's nut while it is rolling. The first nut to crack or break is declared the loser regardless whether it is the roller's or the hitter's.

Research activities conducted and results/ outputs produced

Poverty reduction in coconut growing communities in the Philippines

In 2002, COGENT, in collaboration with PCA selected three pilot communities in the Philippines to implement the ADB-funded 'Poverty Reduction in Coconut Growing Communities' project. Subsequently, one community-based organization (CBO) was identified in each community to undertake the project's component activities. The three selected community-based organizations were: 1) Malapad Integrated Livelihood Cooperative (MILCO) in Real, Quezon; 2) Bahay Patol Agrarian Reform Beneficiaries-Multi-purpose Cooperative (BPARB MPC) in Caliling, Negros Occidental; and 3) Linabu Coconut Planters Association (LCPA) in Linabu, Misamis Oriental.

The three CBOs had a total of 383 members, 55% of which are female. Another satellite community was added during the second year of project implementation with the 357 members of the Fleischer Estate Integrated Marketing Cooperative (FEIMCO) serving as project participants. This satellite community was established in Maitum, Saranggani. Since 2002, about 1496 participants attended various training on coconut nursery management and plant propagation, CBO and microcredit management, processing high-value coconut-based products, livestock /feed production and intercropping, among others. Some farmers and women attended two or more training activities.

Some 334 farmers and women were involved in livestock/poultry production trials consisting of chickens, swine, cattle, and in raising honeybees and fishes; 321 farmers and women are involved in intercropping various food security and cash crops with coconut; and 219 are engaged in processing high-value coconut-based products such as handicrafts and food products. Some farmers and women are engaged in two or more income generating activities. Aside from copra, fresh nuts and toddy, other new high-value coconut products being produced are virgin coconut oil, shell handicrafts, pyroligneous alcohol, sugar, vinegar and various food items from kernel like ‘buko-pie’, ‘bukayo’, boat tart and macaroons. These activities have increased farmers’ incomes by 2-3 times.

More than 200 farmers and women were involved in the operations of the community-based nurseries. There were seven community-managed nurseries established during the project, five were solely coconut nurseries and two were integrated nurseries for coconut, fruit trees and other crops. These nurseries produced a total of 28 174 seednuts of various coconut varieties, some were introductions from the government’s Coconut Research Stations and others were taken from selected high-value high-yielding coconut palms in the locality. These local varieties were characterized, identified and paint-marked during the characterization done with the help of PCA using a participatory farmers’ variety characterization process and COGENT’s standardized coconut breeding techniques (STANTECH) protocol. About 23 000 seedlings have been planted by the CBO members in the project sites as part of strategy to promote on-farm conservation of coconut diversity. The nurseries have also produced more than 7000 seedlings of mixed species of forest and fruit trees.

The country project has published and distributed seven technoguides, four CBO project fact sheets and published one article in a national monthly magazine. It has made presentations and briefings to seven meetings, conferences and televised interview. The project has distributed 12 technoguides from the PCA’s recent research outputs. This public awareness campaign is envisaged to generate interest from the government, private sector and other development organizations to provide support, either in expansion of activities within the current project sites or in replicating similar project in other coconut growing communities in the country. It was also aimed at promoting viable technologies that can help other farmers to increase their farm productivity and income. Encouraged by the initial successes, the project will be replicated in Nabas, Aklan; Tanjay, Negros Oriental; Sanchez Mira, Cagayan; and Biliran, Biliran.

Coconut embryo culture and somatic embryogenesis

With the aim of improving, standardizing and upgrading the coconut embryo culture protocol, the Tissue Culture Division of PCA at the Albay Research Center led a COGENT-funded collaborative project to enable the mass production of the soft-endosperm Makapuno; rescue of Lono varieties; and develop a reliable protocol for micropropagation of superior coconut palms through somatic embryogenesis.

The use of improved coconut embryo culture protocol ensured a conversion rate of at least 50% from embryo to field-ready palms when used for the mass production of Makapuno planting materials and rescue of Lono embryos. Recent findings of Australian Center for International Agricultural Rresearch (ACIAR)-funded project showed that three months old embryo cultured coconuts are capable of autotrophic development and can already be established *ex vitro*. The use of soil-coco coir dust mix (1:1) as soil support and a humidity tent which provide large headspace for the plants during soil establishment resulted to 100% survival of three month old seedlings.

The establishment of selection criteria to identify highly competent callus lines (HCCL) which possess high potential to convert into somatic embryos had a significant result of the current research on clonal propagation of coconut. Modification of the cultured media and cutting of cultures into smaller pieces successfully multiplied the HCCL. The use of higher sugar level resulted to clumps of individualized globular calli which are deemed as desirable starting materials for induction of high quality somatic embryos.

The increased success rate of Makapuno embryos through the upgraded protocol, assured augmented supply of embryo-derived Makapuno planting materials for the coconut farmers. Current activities to shorten the Makapuno embryo culture cycle from 8-12 months to 6-9 months is expected to cut back the production cost by approximately 30%. This finding will reduce the current price of embryo cultured Makapuno closer to the buying capability of small coconut farmers. The continuous production of Lono bearing palms using embryo culture technique will pave the way for establishing Lono type plantation in PCA-Albay Research Center.

The establishment of selection criteria to identify HCCL will guide researchers to pinpoint the correct cultures to nurture. The identification of proper treatments to multiply and ensure desired development of these HCCL and the ongoing search for media additives will ensure their conversion to somatic embryos though a reliable micropropagation protocol for coconut. Normal development is so far observed on field-planted clones derived from inflorescence and plumule reducing the probability of somaclonal variation on these clones. Once developed, the clonal propagation protocol will pave the way for the availability of superior coconut planting materials.

Development of molecular diagnostics for Coconut *Cadang-cadang* Disease: Application of biotechnology to coconut crop protection in the Philippines

Cadang-cadang is a fatal disease of coconut found mainly in the Bicol Peninsula, Masbate, Catanduanes, Samar and in isolated areas in Quezon. It is caused by a viroid referred to as the Coconut *Cadang-cadang* Viroid (CCCVd). Economic losses arise from the cessation of nut production on diseased palms. The presence of the disease has also caused problems in international trade of coconut products from the Philippines.

There is no direct method of control for the CCCVd. As *Cadang-cadang* develops slowly in coconut palms, diagnosis by symptoms alone is often unreliable particularly at a single observation. Since viroids do not code for any protein nor are they encapsidated by protein, serological methods cannot be used for viroid screening. However, since viroid structure and pathogenecity are governed by the nucleotide sequence, nucleic acid tests are ideal for disease indexing.

Studies were done to develop diagnostic tests to facilitate studies geared towards the establishment of appropriate preventive control measures. Simple, sensitive and rapid assay techniques for sample preparation, viroid purification and detection were developed and standardized to achieve best results in *Cadang-cadang* diagnosis. Electrophoretic techniques detect viroids on the bases of size and thermodynamic properties. Modifications have been done to simplify/ miniaturize the procedure and at the same time improve its sensitivity. Polyacrylamide gel electrophoresis (PAGE) using slab gels allowed optimum resolution of CCCVd and its sequence variants. Gel staining using silver nitrate instead of toluidine blue increased detection sensitivity more than 100 times.

A one-tube Reverse Transcriptase/Polymerase Chain Reaction (PT/ PCR) analysis has also been developed for CCCVd detection. A system was designed where all the components necessary for both reverse transcriptase and polymerase chain reaction (PCR) are combined in a single tube, and two reactions carried out sequentially in a single thermal cycling programme. The antisense DNA primers selected for use in the PCR also serve to prime specifically for the reverse transcription. Although more expensive that the other techniques, it provides a rapid, specific and highly sensitive diagnostic technique for detection of CCCVd and related viroids.

The diagnostic techniques for CCCVd have been applied for regular indexing of palms used in CCCVd transmission, epidemiology, molecular variation, resistance screening and host range studies. Intensive monitoring of CCCVd spread and distribution is now made easy even in remote survey sites. The availability of simple, reliable and cost efficient disease diagnosis techniques has facilitated the development of various avenues for disease control. Early detection on symptom-less palms and those at the very early stage of the disease have provided more accurate epidemiological data. In the absence of specific control measures for *Cadang-cadang,* early detection followed by eradication (cutting and burning) of disease palms will help minimize the spread of infection. CCCVd mutation in the field can be recognized and monitored effectively. Exploration into disease resistance and tolerance, vector control and mild strain protection can now be pursued.

The developed molecular techniques have also been used to satisfy quarantine requirements related to *Cadang-cadang* (*i.e*. verification of possible CCCVd contamination in coconut-based food and non-food coconut products for export). Molecular hybridization assay confirmed the absence in CCCVd in the solid and liquid endosperm as well as in food products obtained from the coconut meat and water. Products and by-products from the coconut meat and water, therefore, do not provide any risk of disease transmission. Although CCCVd has been detected in coconut husk, by-products from mature husk (coir and fiber) are also risk-free as the husk is composed of practically dead tissues and the viroid cannot survive the additional exposure to processing conditions.

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Southeast and East Asia

Status of coconut genetic resources research in China

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Introduction

In China, because of the cold weather, coconut palms can only grow in the country's southern parts, mainly in Hainan Province, parts of Yunnan Province and in Guangdong Province. A few coconut palms are sporadically distributed in Guangxi Province in the southwest and Fujian Province in the southeast (Li Yuandao 1988). The total area under coconut in the country is about 70 000 hectares.

Two main factors hinder the development of the coconut industry in China: (1) the long and economically unproductive growing period; and (2) the low economic return on a per unit area basis (Mao Zushun 1998). Therefore, it is essential to breed improved varieties and to adopt a sustainable farming system to strengthen the development of coconut.

Since 1994, some international collaborative projects spearheaded by the Coconut Research Institute of Chinese Academy of Tropical Agricultural Science (CRICATAS) had been implemented in China, with the support of the International Plant Genetic Resources Institute's International Coconut Genetic Resources Network (IPGRI-COGENT), with funding from the Asian Development Bank (ADB). These projects include technical missions, training courses, meetings, workshops and coconut-related research activities.

Research activities conducted

Under the projects supported by COGENT, 17 accessions of cold-tolerant coconut germplasm in Hainan, Yunnan and Guangdong Provinces were collected, evaluated and conserved. These accessions include 14 Hainan Tall (HNT), two Yunnan Tall (YNT) and one Guangdong Tall (GDT). Hainan Tall was collected from Hainan Island, considered the main coconut growing area in China, which is close to the northern marginal limit latitude 20°N for coconut palms. It is a site of particular interest to coconut breeders for screening cold-tolerance. On the other hand, the YNT materials came from Yunnan Province, one coming from Jinhong City (22°N, precipitation 1148 mm, mean temperature of 22°C) and another from the Olive Dam area (21.7°N, precipitation 1540 mm, mean temperature of 21.9°C). Most of the coconut palms in these areas have good average yields, even higher than that in Hainan Island. The GDT came from the southern part of Guangdong Province, close to Hainan Island. There are a few districts in the province such as in Xuwen (20.2°N, precipitation 1218 mm, mean temperature 23.2°C) where coconut palms can grow normally. Their behaviour is almost similar to those growing in Hainan Island, but palms in farther inland bear fewer nuts.

All the accessions mentioned above are conserved in the coconut genebank of CRICATAS in Wenchang City of Hainan Island. Part of the passport and characterization data has been submitted to the International Coconut Genetic Resources Database (CGRD). The rest of the data, including molecular markers, would be submitted as soon as they are completed.

With support from the International Fund for Agricultural Development (IFAD), CRICATAS documented the different intercropping practices in China as well as from other countries. These were aimed at recommending suitable intercropping patterns, making a systematic study and disseminating intercropping techniques to smallholder farmers to enhance their on-farm incomes. Meanwhile, some of the more successful intercropping technologies documented are being applied in CRICATAS' coconut genebank to generate financial support for the genebank's maintenance. This has resulted in a well-maintained and expanded genebank which houses not only the cold-tolerant varieties collected in China but also varieties obtained from other countries. Under the IFAD-funded project, the following activities were undertaken:

1. Conducted a market survey to identify and quantify marketable products from intercrops;
2. Reviewed and documented promising coconut intercropping practices in China and abroad, and based on these observations, formulated suitable intercropping technologies for Hainan Island;
3. Established intercropping trials and evaluated the patterns of selected intercropping technologies in the coconut seedgarden in Wenchang;
4. Conducted a cost and return analysis of these intercropping technologies and formulated a recommendation on a coconut-based farming system to generate funds to support the coconut genebank as well as to help farmers' increase their on-farm incomes;
5. Evaluated the social and economic benefits of the project to the community;
6. Trained smallholders on different intercropping techniques in new and existing coconut plantations;

7. Conserved and used newly collected cold-wind-resistant coconut genetic resources by intercropping to make full use of land and other farm resources; and
8. Disseminated and deployed economically-valuable coconut diversity, developed new and diversified high-value products and recipes.

Under the project funded by Department for International Development (DFID) of the UK, a framework was established and project sites were selected for deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Hainan, China.

In 1994, a coconut expert was sent by COGENT to China to assess the country's R&D capability as well as assist the national programme in identifying common problems, opportunities and projects for network collaboration. In addition, two CRICATAS technical staff were sponsored by COGENT in 1999 and 2001 to undergo training in coconut data analysis and on the use of the STANTECH (Standardized Research Techniques in Coconut Breeding) manual, microsatellite kit and dedicated software.

Project results/outputs

The results of ADB-funded COGENT projects show that the predominant coconut varieties grown in China are the local Talls, which are morphologically diverse. Further studies revealed that China did not have local Dwarf types. Therefore, for purposes of hybrid production, some high-yielding Dwarf varieties from other countries have been introduced to be used as female parents.

Among the local Talls, green-brown is the common colour of the seedling sprouts, leaf stalks, inflorescence and the immature fruits. When the fruits are young (six to nine months), their colour is often pale green or brown. These local Talls usually have the biggest nuts, thickest and tallest stems, widest canopies and longest leaves among all the coconut varieties found in the country. They are also very tolerant to diseases, hurricanes and cold. The weight of fresh fruit ranges from 1.5 to 4 kg; whereas the dried fruit is about 1 to 2.5 kg. The nut shape is round, with most palms producing green-coloured fruits except a few that yield reddish or brownish nuts (Mao Zushun 1986; Tang Longxiang 1999).

Luc Baudouin of the Centre Institut de Recherche Agronomique pour le Developpement (CIRAD) analysed HNT as well as other Talls from Southeast Asia, specially those from Vietnam, Thailand, Kampuchea and Malaysia, using microsatellites (Baudouin 2002) .

In search for materials that are highly-tolerant to cold and/or drought, it was recognized that no other coconut producing country in the world has the same diverse ecological condition as that prevailing in Hainan.

The IFAD-funded projects helped to identify and establish effective coconut-based farming systems and deploy coconut diversity through the following activities:

1. Identification of marketable and profitable intercrops/ intercrop combinations under coconut such as cocoa, grass (as feed), vegetable, horticultural flowers and plants, banana, areca, tea, areca, pepper, maize, peanut, litchi and mango;
2. Establishment of coconut intercropping trials in the seedgardens of CRICATAS. Different types of grass were interplanted between young and mature coconut palms. Results showed that grass grew well under coconut, and that the coconut palms also grew better compared with non-intercropped palms. Other successful intercrops identified include vegetables, especially hot pepper (chillies). Under mature coconut palms (15 years old), cacao, which has a large potential demand in China, grew well;
3. Conduct of studies on socioeconomics of intercropping, which revealed the following:
   - **Provision of additional income**. The long unproductive period (5-7 years) before coconut palms start to bear fruits makes intercropping more attractive as a feasible alternate and interim source of income from young coconut plantations. Intercropping also leads to a higher cash return than from pure stands of coconut. Additional income from intercrops is particularly useful when there is a loss in coconut yields due to drought, cold wave, pests and diseases infestation, etc.
   - **Increased employment prospects**. Labour required for maintaining coconut is generally low, and therefore intercropping could generate additional employment by increasing the utilization of farm labour throughout the year.
   - **Safety net against market risks.** The variety of crops introduced by intercropping could ensure at least a partial guarantee against market risks and price fluctuations of the coconut crop as farmers would have more alternatives as to what type of crop could be marketed profitably given a specific season or time of the year.
4. Conduct of agronomic desirability studies of coconut intercropping;
   - **Better water retention.** Because of the shade provided by coconut stands, evaporation of water is considerably reduced therefore allowing intercrops to survive better with less irrigation demand.

- **Improved soil fertility.** Organic matter is built up in the soil by the addition of coconut debris, leaf litter, pruned material and post harvest by-products of intercrops. Benefits are more pronounced in coconut/cocoa system, coconut/grass system and coconut/vegetable system. These benefits are primarily due to the increased activity of useful microbes in the soil such as phosphate solubilizers and nitrogen fixers, which is heightened further by the favourable eco-climate.
- **Soil erosion control.** In high rainfall areas, particularly in the southeastern part of Hainan Island, intercropping proved to be effective in checking soil erosion in coastal sandy soil, which comprises a large proportion of intercropped coconut holdings (about 80%) on the island.
- **Better weed control.** Intercropping better controls the spread of weeds in the spaces between stands in coconut lands as the economically useful crops replace the weeds and contributes to decreasing cost of cultivation.
- **Coconut as a shade tree.** Coconut palms, usually the Tall varieties, often serve as an economic shade tree, particularly for shade-loving crops such as cacao, coffee, black pepper, ginger and some types of grass.

5. Publication of Catalogue of High-value Coconut Products, which contains and discusses the main coconut-based products produced in China, including their production processes and their marketing/pricing; would accelerate technology adoption.
6. Identification of new project sites for replication of coconut-based poverty reduction projects. Five coconut growing communities have been selected as new project sites for deployment of coconut-based poverty reduction interventions using COGENT's 3-pronged strategy. A total of 313 coconut farmer families were surveyed and socio-economic data on these communities have been generated. Through these surveys, the poverty situation, constraints, opportunities and appropriate interventions have been defined and analyzed, which will be addressed in the next COGENT-funded project.

Significance or impact of output

China's coconut genetic resources, which are small compared to other coconut-producing countries in the world, are nevertheless very important because of their diversity. The collecting, evaluation and conservation of the country's indigenous and exotic coconut resources has enabled China, through CRICATAS, to cooperate closely with the other member countries of COGENT, contributing to the enrichment of available coconut breeding materials.

Findings of agronomic and socioeconomic studies, particularly related to on-farm technological interventions to increase coconut farm production, would greatly enhance future projects focused on helping coconut farmers increase their incomes and thereby reduce their poverty. Results of intercropping studies would also significantly help coconut producers make effective and efficient use of their land.

Suggested next steps

1. There is a need for China to increase its current coconut germplasm collection in order to conduct more studies to develop the country's coconut genetic resources as well as to meet current and future breeding requirements. Therefore, promising Dwarf varieties from other countries, which could very well serve as female parent in breeding and hybrids production, must be procured and introduced;
2. More characterization and evaluation data of local varieties, especially for cold and wind, would be collected and submitted to the CGRD;
3. To help coconut farmers, successful intercropping technologies would be deployed and new technologies to produce high-value coconut products would be developed; and
4. Relevant international coconut meetings, workshops and training courses should be organized in China.

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Africa and the Indian Ocean

Status of coconut genetic resources research in Côte d'Ivoire

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Introduction

After the Second World War (1939-1945), there was an increased global demand for oil. To meet this demand, many research institutes dealing with oil crops were formed all over the world, particularly in Africa (Benin, Ghana, Côte d'Ivoire and Tanzania). In Côte d'Ivoire, the Centre National de Recherche Agronomique (CNRA) is in charge of agronomic research nationwide. Work conducted by CNRA concerns several crops including coconut.

The Coconut Programme of CNRA is based at its Marc Delorme Research Station in Abidjan in the southern part of the country. About 1000 ha are available for implementing research activities on coconut, which include germplasm, breeding, agronomy and physiology, crop protection, technology and biotechnology.

Much work was carried out in developing the coconut genetic resources of the country, thereby making coconut one of the top perennial crops in Côte d'Ivoire.

To achieve the objectives of the CNRA's Coconut Programme, 53 coconut varieties were introduced from 1967 to 1986. Research activities were implemented mainly in collaboration with the French Government. The success of the projects carried out on coconut is attributed to factors such as social and political stability as well as the absence of serious disease infestations.

Since 1996, the germplasm collection in Côte d'Ivoire became the centrepiece of the International Coconut Genebank for Africa and the Indian Ocean (ICG-AIO). The memorandum of agreement formalizing the establishment of this ICG was signed in 1999 between the International Coconut Genetic Resources Network (COGENT) of the International Plant Genetic Resources Institute (IPGRI) and the Government of Côte d'Ivoire through CNRA, with the Food and Agriculture organization of the United Nations signing as trustee..

In 1970, the Côte d'Ivoire government initiated a nationwide campaign to encourage farmers to plant more coconuts and maximize the use of the crop. To date, the total area planted is estimated to be 50 000 ha. However, the development of the coconut sector has been generally limited due to many constraints, such as:

- Resistance of farmers to adopt and utilize high-yielding coconut hybrids;
- Non implementation of agronomic techniques developed by scientists;
- Occurrence of drought in the eastern and the central parts of the country where most coconuts are planted; and
- Lack of product diversification, especially for high-value products.

Based on these factors, CNRA set the objectives of its Coconut Programme as follows:

- Select and promote adapted and high-yielding varieties, especially those tolerant to biotic and abiotic stresses;
- Initiate appropriate agronomic and crop protection methods to develop the potential of the coconut as a commodity crop;
- Develop appropriate techniques to promote product diversification and processing into high-value products; and
- Provide technical assistance to coconut farmers and training to students.

Research activities

To effectively implement its activities, the CNRA Coconut Programme collaborates with many local and international institutes and organizations such as with IPGRI/COGENT, the Bureau for the Development of Research on Tropical Perennial Crops (BUROTROP) and the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD) being its most strategic partners. Some of the CNRA's most significant projects on coconut genetic resources development in recent years include the following:

- ***Management of coconut genetic resources***. From 1967 to 1986, 53 varieties from the entire inter-tropical zone have been introduced. The establishment of the ICG-AIO and exchange of genetic materials proposed by countries like Sri Lanka are envisioned to increase the number of accessions in the ICG. Presently, 92 accessions are conserved in the field. Morphometric observations are regularly conducted according to the guidelines set in the STANTECH (Standardized research techniques in coconut breeding) Manual. A rehabilitation programme to replace old and senile stands (20 to 30 years old) initiated in 1988 is ongoing. Recently IPGRI/COGENT, with funding from the Global Crop Diversity Trust, is supporting the regeneration of 50 accessions in the ICG-AIO.

- ***Improvement of coconut production.*** Based on recurrent reciprocal selection, two types of hybrids have been developed: Dwarf x Tall and Tall x Tall (Bourdeix *et al.* 1988, 1991). The general and specific combining abilities of the main populations of the collection are being tested using the same scheme.

- ***Research for tolerance against Lethal Yellowing Disease (LYD).*** Thirty (30) varieties and hybrids from CNRA have been tested for resistance to LYD in collaboration with Ghana (under the country's coconut sector development project). So far, seven trials have been conducted (Konan and Allou Kouassi 2002). Although the disease is absent in Côte d'Ivoire, a team of scientists from CNRA regularly visits the trials in Ghana to monitor the disease and to develop strategies for control in the fields. In the future, more varieties and hybrids from CNRA will be tested in infested zones in Ghana.

- ***Varietal improvement for drought tolerance.*** Physiological characteristics and production performance under drought conditions of young and old coconut varieties and hybrids are currently under study at Marc Delorme Research Station (Konan 1997; Repellin 1994; Repellin *et al.* 1994). Results of this study would help determine what varieties or hybrids would be most appropriate for planting in drought-stricken areas. Additional data from drier areas are still being collected to confirm initial results.

- ***Multilocation trials to identify suitable coconut hybrids and varieties for Africa, Latin America and the Caribbean (1999-2004):*** Seven countries, namely: Côte d'Ivoire, Benin, Tanzania, and Mozambique in Africa; Mexico and Brazil in Latin America; and Jamaica in the Caribbean, are involved in the implementation of this Common Fund for Commodities (CFC)-funded project, which is a collaborative undertaking between, IPGRI-COGENT, CFC and the Portuguese (funding Mozambique) Governments. As of 2003, all the participating countries have tested 10 hybrids, six of which were produced from Côte d'Ivoire (Konan 2002). The project is aimed at identifying the hybrids or varieties suited to a particular agronomic condition existing in a country.

- ***Improvement of collection and genetic data management.*** Data collected from genetic resources experiments and germplasm evaluations are registered in obsolete software (i.e., IGK and Predec). This project aims to transfer these data into new, more efficient databases (i.e., CGRD, CDM, Geneclass) developed by CIRAD. Current data are now being entered into these new databases.

- ***Biotechnology.*** Activities concerning this area are conducted in collaboration with CIRAD and the Institut de Recherche pour le Developpement (IRD) based in Montpellier, France. These involve molecular characterization of genetic resource (Lebrun *et al.* 2001), *in vitro* culture of embryos (Assy Bah 1986) and cryopreservation. In April 2003, with funding from IPGRI/COGENT, Dr Jean-Louis Konan, head of the CNRA Coconut Programme and Mr Jean-Noël Kouame, a graduate student, were trained on coconut genetic resources management and analysis using microsatellite kit and dedicated statistical software. Through a research grant from IPGRI/ COGENT, the microsatellite technique is presently being applied at the CNRA biotechnology laboratory. It is hoped that other regional members of ICG-AIO would be trained on the use of the technique in the future.

- ***Intercropping coconut with acacia.*** Since 1984, several leguminous species were evaluated for soil fertility improvement in the coastal areas. Studies have shown that *Acacia mangium* and A. *auriculiformis* are the best species to improve the fertility of sandy soils of such areas. Intercropping *Acacia* with the coconut hybrid PB121 increased the production of coconuts by 10-fold (at least 10 000 nuts/ha) as compared to 1000 nuts/ha yield without *Acacia* (Zakra *et al.* 1996). The intercropping technique is being promoted to re-establish coconut plantations along the coastal areas.

- ***Development of biological techniques against* Oryctes monoceros**. Different chemicals have been traditionally used for controlling *Oryctes* (Kouassi *et al.* 2002), which is very expensive for farmers and dangerous to the environment. CNRA studies have shown that pheromone could be used to control *Oryctes* in coconut fields, which is more effective and cheaper than using inorganic products. A similar technique is being developed against *Rynchophorus*.

- ***Diversification of processed coconut products.*** Coconuts produced in Côte d'Ivoire are mainly exported either as copra or as oil. Other parts such as the husk, shell, water, wood and leaves are not being fully utilized. Processing techniques are being developed to maximize and diversify the use of these parts, specifically to produce high-value products.

Research results/ outputs and their significance

- Research studies to increase coconut productivity in Côte d'Ivoire have led to an increase in copra production per unit area from an average of 0.6 t/ha/year to 4 t/ha/year in agro-industrial plantation. In the research station, the production is now more than 5.5 t/ha/year (Bourdeix *et al*. 1992);
- The high-yielding hybrid PB121, which was produced in the country, is believed to be the most widely adopted variety;
- Coconut experiments by CNRA have identified two varieties, Sri Lanka Green Dwarf and Vanuatu Tall, as being highly tolerant to LYD in Ghana. The CNRA is now producing hybrids using these varieties as parents for propagation in Ghana to check the spread and destruction of the disease;
- Based on the results of agronomic studies, *Puerarria* and *Acacia* are being intercropped with coconut to increase production. Coconut husks, which are traditionally regarded as farm waste, are now being used as mulch and organic fertilizer. These technologies are being transferred to farmers for eventual application in the field; and
- Many crop protection techniques developed in Côte d'Ivoire (e.g. mechanical, chemical or biological controls, etc) have contributed to increasing the productivity of the coconut.

Future plans

To further strengthen research activities to meet the increasing demand of the coconut sector in the country, CNRA would undertake the following activities in the next few years:

- Increase its collection by 200 accessions by procuring new materials from other countries;
- Increase the collection in the ICG-AIO through *in vitro* conservation and duplicate the site at Sassandra, located 300 km from the present site;
- Continue with its multilocation hybrid trial to select high-yielding hybrids adapted to different agro-climatic conditions;
- Continue to improve data collection and information management system using CGRD, CDM and Geneclass databases;
- Conduct further studies to improve the tolerance of coconut against LYD, in collaboration with Latin America and Caribbean (LAC) countries affected by the disease (i.e., Ghana, Mozambique, Tanzania, Jamaica and Mexico);

- Further promote the adoption of coconut-Acacia intercropping systems to restore soil fertility and increase coconut productivity in the country's coastal areas;
- Conduct further studies to improve crop protection techniques (i.e., use of pheromones against *Oryctes*, use of phosphoric acid against *Phytophthora*, etc.);
- Introduce new techniques into coconut selection scheme;
- Develop new technologies to further promote the processing and diversification of coconut products;
- Improve *in vitro* culture and cryopreservation techniques to maintain coconut germplasm health;
- Establish more collaboration and partnerships with national and international organizations to further develop the country's coconut sector;
- Develop new coconut seed production techniques suited to small-scale farmers and communities; and
- Produce more publications and public awareness materials on coconut to generate more support for research activities on the crop.

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Africa and Indian Ocean

Status of coconut genetic resources research in Ghana

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Introduction

The coconut palm (*Cocos nucifera* L.) was introduced into Ghana probably from the Cape Verde Island around the 15th century (Harries 1977). The cultivation of coconut as an estate crop was initially concentrated around Keta, in southeast Ghana, from where it spread to the rest of the country (Wills 1962).

Coconut is considered to be a very important economic crop in the coastal regions of Ghana, especially in the rural communities, and is fast gaining popularity in many peri-urban communities where it is grown mainly for its refreshing water.

The International Coconut Genetic Resources Network (COGENT) has been a key player in efforts to enhance the conservation and utilization of Ghana's coconut genetic resources.

Research activities, results and significance

Training

COGENT's involvement in Ghana's coconut research and development started in 1997 with the sponsorship of a coconut breeder (Mr Owusu Nipah) to participate in the Regional STANTECH (Standardized research techniques in coconut breeding) Trainer's course for Africa in Abidjan, Côte d'Ivoire. The course was very timely and important as the characterization and even the nomenclature of coconut varieties in Ghana, to say the least, were chaotic. Different departments were using different characters to describe the same variety and then proceeded to give different names. The course gave Ghana the opportunity and the technical knowledge to harmonize research methodologies in breeding and agronomy.

On his return, Mr Nipah organized two training courses for coconut researchers and technical officers in Ghana on the use of the STANTECH Manual and the International Coconut Genetic Resources Database (CGRD). These training sessions formalized and unified terminologies and methodologies in coconut R&D in Ghana. Information provided by the CGRD, which is updated periodically by COGENT, has also given the country's researchers invaluable knowledge about coconut germplasm around the world which can be easily accessed for coconut R&D needs of the country. In the future, Ghana intends to characterize all of its coconut germplasm and incorporate the data generated into the CGRD.

Technical assistance

In March 1998, COGENT sponsored a trip by a coconut expert, Dr YP N'Cho, to Ghana to help the country identify its coconut research and development needs, and to formulate an Africa/Indian Ocean coconut regional project proposal, which led to the development of a research proposal on Lethal Yellowing Disease (LYD).

In terms of coconut research, the Ministry of Food and Agriculture has conducted research on drought resistance and started characterizing the Sri Lanka Green Dwarf (SGD) x Vanuatu Tall (VTT) hybrid which Ghana is screening for LYD tolerance.

Although the regional project is yet to be launched, the characterization of SGD x VTT is progressing steadily and should this hybrid prove to be tolerant to LYD, its yield performance will be further evaluated.

Completed/ongoing projects

In May 2001, Ghana, with support from COGENT, undertook a research entitled 'Establishing a framework and selecting project sites for the nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities' using COGENT's 3-pronged strategy for increasing farmers' incomes. The project was funded by the Department for International Development (DFID) and the Government of Ghana.

This project was strategic as its objectives were to determine the income levels of coconut farmers, the types of products they produce, varieties cultivated and the farming systems in place. These were determined to enable the deployment of appropriate technologies for poverty alleviation in coconut farming communities.

The study showed that coconut farmers were mainly illiterate and poor with incomes ranging from US$ 42.83 to US$ 142.32 a year. Reasons for these low incomes were the low yields in farmers' fields (in some cases as low as 1.76 t/ha/yr) and that farmers produced only coconut oil. Gender bias was also observed, with 84.7% of farm owners being male. The study also identified high-value coconut products that farmers were interested to produce to augment their incomes (Dery *et al.* 2001).

Based on the results of this study, a subsequent project entitled 'Developing sustainable coconut-based income generating technologies in poor rural communities in Ghana' was prepared and submitted to COGENT for funding (Dery and Ofori 2002). This would build upon the findings of the previous study in developing appropriate means and interventions to help farmers alleviate their poverty. The local government units of the sites where this project is proposed to be carried out have pledged their support to help this project succeed. While waiting for donor funding, financial support will be sought from the Department of Local Government to deploy some of the village-level technologies already identified for high-value products production. To date, COGENT supports the implementation of this project in one coconut growing community with funding from the International Fund for Agricultural Development (IFAD).

Other research activities

Exploration, collecting, characterization and conservation of coconut genetic resources

The devastating spread of lethal yellowing disease (LYD) in Ghana poses a serious threat to coconut germplasm in the country, especially in the coastal zone where the disease is very prevalent (Dery and Ofori 2000). As coconut was introduced into the country at different times and places by sailor-traders who landed on the shores of Ghana, even the untrained eye can see the significant variation among the unselected landrace collectively called, West African Tall (WAT). Perhaps a consequence of this is the fact that a field devastated by LYD is usually left with some surviving trees. These may be mere 'escapees' or they could be tolerant ecotypes.

With funding from the World Bank under the Agricultural Services Sub-sector Investment Project (AgSSIP), Ghana has started a project to explore devastated farms and collect the 'escapees' for screening for LYD tolerance. Characterization of the different sub-populations of WAT will also be done.

To safeguard Ghana's germplasm, coconut varieties and identifiable sub-populations of varieties from the coastal areas are being propagated and transferred to a field genebank in the hinterlands, at the Oil Palm Research Institute, where they are conserved. There is a plan to replicate this genebank at a sister institute – the Plant Genetic Resources Centre. This project is important because it aims to conserve farmers' varieties, with the added possible benefit of finding an 'escapee' population tolerant to LYD.

Vanuatu Tall subpopulations

From LYD-resistance screening trials conducted since 1982, it has been established that the VTT is relatively tolerant to LYD (also locally known as Cape St. Paul Wilt disease or CSPWD) (Dery *et al.* 1995).

However, the VTT population in Ghana, which was introduced from Côte d'Ivoire, is quite variable (Bourdeix 2000). Harries (1995) also confirmed the general variability of VTT. Because of this variability, which is clearly manifested within the 400 VTT parental palms in Côte d'Ivoire from which the Ghana materials were derived, Bourdeix (2000) suspected that not all of the 400 VTT palms in Côte d'Ivoire could be tolerant to the disease. A full diallel crossing programme was thus designed to separate the sub-populations and to subsequently screen the progenies for LYD tolerance as well as to test their general combining abilities.

Since controlled pollination in coconut, in general, yields fewer nuts per bunch, than the naturally pollinated ones, a modified-assisted pollination method that involves emasculating all other palms in the isolated field and pollinating the VTT palms with selected pollen was carried out for a specific period. The identity of the pollen being used is thus safeguarded without having to bag the inflorescence. The project is being funded by Agence Francais de Developpment under the Coconut Sector Development Project.

Evaluation of coconut progenies for high yield and tolerance to CSPWD

This project involves introduction of new varieties, hybridization of varieties and collection of survivors from devastated farms. These are then screened for high yield and CSPWD tolerance. Presently a total of 38 coconut progenies and disease 'escapes' are being screened at seven locations.

CSPWD epidemiology and vector studies

The management/control of the CSPWD requires a thorough understanding of the disease. Studies are therefore being carried out on the following:

- Vector identification;
- Alternate hosts of the CSPWD phytoplasma;
- CSPWD phytoplasma variability;
- CSPWD latent period; and
- Transmission of phytoplasma through the embryo

These studies are being conducted in collaboration with the Perenniel Crops Department of CIRAD.

Coconut-based cropping systems

About 90% of mature coconut farms in Ghana are maintained as monocrops, while intercropping is done only in the first 3-4 years of planting. Thus, an intercropping project is being carried out both on farm and on station. Systems being studied are:

- Coconut + Citrus
- Coconut + Rubber
- Coconut + Cocoa
- Coconut + food crops (cassava, maize, pepper)

There is also a study on coconut yield enhancement through the application of rock phosphate

Coconut pest control

Two of the most important pests of coconut in Ghana are *Oryctes monoceros* and termites. These are especially important in young palms where mortality very often exceed 50% if no control measures are taken. Trials are underway to develop appropriate control measures. Preliminary results are very promising

Improvement of nuts/inflorescence in controlled pollination in coconut.

The bagging of coconut inflorescence during controlled pollination usually results in a few nuts/inflorescence. A researcher is carrying out investigations to improve nut numbers during controlled pollination. The thesis is being supervised by the University of Nothingham, UK.

Future plans

Climatic changes have resulted in hitherto favourable coconut growing zones becoming drier. Competition with other crops, especially rubber and oil palm, is also pushing the coconut into marginal zones where drought conditions prevail. It is therefore planned to acquire more coconut germplasm to screen for drought tolerant varieties suitable for these zones.

The conservation of farmers' varieties is very important if we are to maintain the genetic diversity of coconut in Ghana. The Coconut Programme intends to promote the multipurpose use of coconut to ensure that each type of coconut is economically viable and therefore preserved by farmers. This will reduce the need to establish expensive field genebanks.

The purity of our coconut accessions will be investigated using the microsatellite technique. This will be done in collaboration with CIRAD.

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Africa and Indian Ocean

Status of coconut genetic resources research in Nigeria

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Introduction

Although the coconut palm (*Cocos nucifera* L.) is not indigenous to Nigeria, an estimated 15 000 hectares of land are under coconut cultivation in the country, mostly in the coastal areas of Lagos State and the delta areas of Rivers State. Another estimated 1.2 million hectares have been identified as suitable for coconut cultivation. The crop is found mostly along the sandy shores of the Atlantic coastlines where it occurs as dense groves, as well as in the riverine areas of the delta regions and to a lesser extent in the inland forest zone. More than 90% of the nation's coconut belt is a continuation of the plantations or groves along the West African Coast, running from Cote d'Ivoire and southwards through Ghana, Togo and Benin to Lagos State in Nigeria where it continues in a one-kilometer wide strip of groves inland along some 200 kilometres of coastline. Coconut cultivated outside these coastal groves is predominantly grown as a compound or homestead crop, with a variety of crops interplanted between the coconut stands to maximize land use. More than 50% of the coconut area is planted to the Tall variety which can best be described as adapted West African Tall (WAT) land races. Dwarf cultivars, on the other hand, are planted mostly as ornamental compound trees.

Coconut holdings in Nigeria are characteristically low in productivity. Virtually all plantings of the WAT varieties are low-yielding with annual production of 3 – 4 metric tonnes (6000 – 8000 nuts) in contrast to the improved hybrid (Dwarf x Tall) which yields 8 – 10 metric tonnes (16 000 – 20 000 nuts) per hectare per year. The low productivity of these holdings are also the result of poor management practices, high density plantings in the groves, poor soil fertility, lack of fertilizer use, prevalence of diseases and high level of mismatched intercrops. Very limited area is planted with improved coconut varieties. They are mostly grown on traditional and family smallholdings, ranging from 0.5 to 1 ha. Recently, however, there has been an increased awareness of the higher productivity of the hybrid coconut varieties resulting in increased demand. Plantations of up to 10 ha on individual or cooperatively-owned farms have been established, mostly in Lagos State.

Research activities conducted and outputs

The Nigerian Institute for Oil Palm Research (NIFOR) is mandated to carry out national research on coconut. NIFOR has identified the spread of Awka Wilt lethal yellowing disease (LYD) as the major threat in the development of the coconut industry in Nigeria. The incidence of the disease is estimated at 8 – 10% in the inland areas and about 5% in the coastal areas of Lagos State, an area hitherto considered to be free from the disease. The control of the Akwa Wilt disease through the production of resistant and highly productive hybrid cultivars; the development of efficient production and post harvest processing methods, and sustainable intercropping systems are the main focus of the institute's coconut research efforts. To this end research has been carried out on the following:

1. **The control of Awka Wilt lethal yellowing disease through the development of high-yielding, disease-resistant hybrid varieties.** The introduced Malayan Green Dwarf (MGD) cultivars in the NIFOR programme has been found to be resistant while the Tall cultivar is susceptible to Awka Wilt LYD. The parental source of tolerant/resistant Tall cultivar is the present limitation in the production of resistant hybrids.
2. **Studies on the aetiology of the Awka Wilt disease and the development of efficient screening techniques.** The Awka Wilt disease has been identified to have the same aetiology as the Cape St. Paul Wilt of Ghana. Understanding the host-pathogen relationship is critical to the development of efficient screening techniques. To this effect, the NIFOR is evolving close research collaboration with the Coconut Research Programme of Ghana to enhance its capacity.
3. **Studies of the fertility management on the coastal and inland soils**. Inorganic and organic fertilizer requirements of the coconut on coastal and inland soils in Nigeria have been studied to a great extent. On-farm adaptive research trials have been carried out to facilitate the adoption of recommendations by farmers. Because of the prohibitive cost of conventional chemical fertilizers, the current focus is on the development of the locally available mineral deposits as cheap sources of fertilizers and the development of an integrated method of composting, easily adaptable to the farmers' environment and socio-cultural and economic conditions.
4. **Development of sustainable coconut-based intercropping systems.** Coconut-based food crop intercropping systems have been shown to be the most economically-viable method of maximizing the smallholdings of the coconut farmers. The most efficient se-

quence of intercropping with arable food crops, and water and soil nutrient management methods for the various ecologies are being developed to enhance sustainability of the intercropping systems which the farmers already practice.

5. **Development of efficient postharvest technologies.** The development of small-scale tools to enhance the efficiency of the farmer and add value to his/her products and income is a major focus of the NIFOR's research thrust. To this end, the Institute has developed small-scale tools for efficient dehusking of the coconut, mat weaving, meat grating, copra drying, crushing, oil extraction and shell distillation.

Research constraints and opportunities

Despite limited research funding, the NIFOR's coconut research programme has recorded major achievements. However, future progress will depend to a great extent on the Institute's present effort to combat the spread of the Awka Wilt LYD. The main research needs identified include:

1. The expansion of the very limited genetic base of the NIFOR coconut breeding population to include new high-yielding MGD genotypes and LYD-resistant Tall cultivars. Related to this, Nigeria must be involved in the International Coconut Genetic Resources Network (COGENT)-coordinated international programme on germplasm exchange and evaluation;
2. The basic infrastructure required for the LYD aetiology studies are not available to NIFOR's scientists. The Institute's laboratory facilities and equipment need urgent upgrading;
3. Nigerian coconut scientists need to undergo training and capacity building to be acquainted with current developments in coconut genetic resources research; and
4. The NIFOR tools workshop needs to be better equipped to effectively support the post-harvest technology development programme of the institute.

Suggested next steps

From 8 to 12 May 2000, the NIFOR participated in the Second International Coconut Workshop for Africa in Mombassa, Kenya. At this conference, a significant decision was made by stakeholders for Nigeria, through NIFOR, to lead the interregional research on coconut intercropping. It is hoped that this proposal will be realized in the coming years.

Africa and Indian Ocean

Status of coconut genetic resources research in Tanzania

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Introduction

The coconut palm (*Cocos nucifera* L.) is an important perennial cash and subsistence oil crop along the coastal belt of Tanzania, where about 25 million palms are cultivated on approximately 252 000 ha. The crop supports the livelihood of more than 300 000 rural households, with an average farm size of 0.5 to1 ha. The coconut is an agroforestry crop that provides food, cash, shelter, job opportunities and conserves the fragile coastal belt ecosystem. The crop is also cultivated inland especially in the Morogoro region and along the shores of Lakes Nyasa, Tanganyika and Victoria.

It is estimated that each household in traditional coconut growing areas consume about three to four nuts per day. This high demand cannot be met due to low and declining production that became more apparent during the late 1960s and early 1970s. Some of the major constraints that contributed to this decline include the presence of serious pests and diseases, poor crop husbandry practices as a result of inadequate extension services to growers, lack of improved planting materials, ageing coconut palms, sub-optimal climatic conditions as well as lack of institutional set-up to promote/support coconut research and development activities.

It is against this background that the Government of Tanzania decided to initiate the National Coconut Development Programme (NCDP) in 1979/80 with the mandate to promote coconut production and utilization, and to improve the productivity of the coconut sector in the country. The inception of the NCDP marked the beginning of the process of institutionalizing coconut R&D in the country, which led to the establishment of the Mikocheni Agricultural Research Institute (MARI) in 1996. Apart from implementing the NCDP, Tanzania has been collaborating with regional and international organizations such as the International Coconut Genetic Resources Network (COGENT) of the International Plant Genetic Resources Institute (IPGRI), the Bureau for the Development of Research in Tropical Perennial Oil Crops (BUROTROP) and other donor agencies in the implementation of a number of R&D projects on coconuts. This country report covers the coconut projects that have been implemented or initiated since 1990.

Research activities conducted and outputs

Completed COGENT-assisted projects

Improvement of *in vitro* techniques for collecting and exchange of coconut germplasm

MARI collaborated with 11 institutions from other countries from 1998 to 2001 in the development of improved and standardized embryo culture and acclimatization techniques. The project was funded by the Department for International Development (DFID) of the United Kingdom . Through this project, MARI improved its efficiency and capacity in *in vitro* coconut embryo culture techniques.

Establishing a framework and selecting project sites for a nationwide deployment of coconut-based poverty reduction interventions

This is a project that was funded by DFID and implemented in 15 coconut producing countries, including Tanzania, with the objective of defining the poverty situation, constraints, opportunities and the technological interventions required for diversity-linked poverty reduction interventions. The country reports were further discussed in a workshop organized by COGENT in Ho Chi Minh City, Vietnam from 25 February to 1 March 2002 and used to develop a project proposal titled 'Overcoming poverty in coconut growing communities' as a strategy to promote poverty reduction and on-farm conservation of coconut genetic resources for funding submission to the International Fund for Agricultural Development (IFAD). This project is now funded (2005-2008) for implementation in one coconut growing community in Tanzania.

Multilocation variety trials (MLVT) to identify suitable hybrids/varieties for Africa, Latin America and the Caribbean

One of the major constraints to coconut production in Tanzania is the lack of improved high-yielding planting materials that are adapted to prevailing local conditions. To address this, Tanzania has embarked on a national breeding programme, the overall objective of which is to develop varieties with improved yield as well as high resistance or tolerance to lethal disease and drought. Tanzania is also collaborating with five other countries in an International Multilocation hybrid trial, which is funded by the Common Fund for Commodities (CFC) and coordinated by IPGRI/COGENT. The other participating countries are Côte d'Ivoire, Benin, Brazil, Mexico and Jamaica. Mozambique has also joined in with financial support from the Government of Portugal. The main objectives of this 5- year project are (2000-2005):

- To assist each participating country in identifying suitable high yielding hybrids/varieties with high adaptation to prevailing local conditions; and
- To estimate genotype x environment (GxE) interaction that would serve as a guide to the application of the results to other countries with similar cultivation conditions.

Each country compared four of its best local hybrids/varieties with six common multi-site control hybrids produced in Côte d'Ivoire, and proven to have good yield potential. The six multi-site imported hybrids (four Dwarf x Tall and two Tall x Tall) and the four local hybrids planted in Tanzania are listed in Table 1.

Table 1. List of multi-site imported hybrids and local genetic materials being evaluated under the multilocation trials in Tanzania

Muti-site (imported) hybrids	Local genetic materials
Malayan Yellow Dwarf x West African Tall	East African Tall x Pemba Red Dwarf[1]
Cameroon Red Dwarf x Rennell Island Tall	East African Tall x Rennell Island Tall
Malayan Red Dwarf x Vanuatu Tall	East African Tall x Vanuatu Tall
Malayan Red Dwarf x Tagnanan Tall	East African Tall
Vanuatu Tall x Tagnanan Tall	
Sri Lanka Tall x Tagnanan Tall	

[1]*The cross PRD x EAT could not be produced due to lack of sufficient PRD palms as seed parent, so a decision was made to produce the reciprocal of this cross instead*

Each basic plot consists of 16 palms, planted in a triangular pattern at 9m between palms in a randomized complete block (RCB) design with five replications. Data recorded include vegetative growth and reproductive parameters. Samples for soil and leaf analysis were taken one and three years after planting, and the results were used as basis for fertilizer application.

Statistical analysis is being done at the country level to compare the different genetic materials, while a combined analysis involving data of all countries will be done after five more years to determine the genotype x environment (GxE) interaction. The 5-year funding of CFC terminated in 2004 but the Government of Tanzania will continue the trial using its own budget. The plants in the trial are growing well and maintenance and data gathering are ongoing.

Other completed projects

From 1990 to date, Tanzania has completed six coconut projects that were initiated by or funded through other organizations, while two projects are still being implemented.

Biotechnology improvement of coconut: Application to breeding and crop protection (1994 – 1997)

In this research project the MARI collaborated with Max Planck Institute for Plant Breeding (MPIZ), Cologne, Germany; the Basque Institute for Agricultural Research and Development (NEIKER) in Spain; and the Philippine Coconut Authority (PCA) under the STD III Programme of the European Union (EU). The main objective of this project was to develop and use DNA marker technology for the characterization of different coconut germplasm and for diagnosing important coconut diseases, in particular the lethal yellowing-type diseases (LYD) caused by phytoplasma and Cadang-cadang disease caused by viroids. The main outputs were:

- Two mapping populations developed;
- DNA markers applied for the estimating the between and within genetic diversity of coconut populations (Rohde *et al*. 1996, 1999);
- Preliminary linkage map of the coconut established;
- PCR techniques developed for the diagnosis of the coconut LYD phytoplasma; and
- MARI's biotechnology capacity enhanced through the provision of laboratory facilities and short-term training of local researchers and technicians.

Sustainable coconut based-farming systems: Operational and economic analysis models (1992 - 1998)

In this project, the NCDP collaborated with Centre de Coopération Internationale en Recherche Agronomique (CIRAD) of France, the Natural Resources Institute (NRI) of UK, PCA, the Philippines, Indonesia and Vanuatu, which was funded by the EU under the STD III Programme. The main objective of this project was to develop operational and economic analysis models for improved coconut-based farming systems. The main outputs of this project included:

- Assessment of the quantity and quality of light transmitted through the coconut canopy in relation to the planting density;
- Development of an economic model for different intercropping systems; and
- Graduate training of a Tanzanian agronomist at the PhD level.

Investigation into the aetiology and control of lethal yellowing type-diseases (1992-1997)

This project aimed to develop molecular techniques for studying the aetiology and epidemiology of LYD of the coconut palm. It was funded by the EU under the STD III Programme, and implemented from 1992-

1997 by the following institutions: MARI, Tanzania; Natural Resources Institute (NRI), UK as the coordinator; CIRAD, France; Ministry of Agriculture, Ghana; and Marc Delorme Coconut Station, Côte d'Ivoire. The main outputs were:

- DNA probes and PCR primers specific for the detection of LYD phytoplasma;
- LYD strains from West Africa were found to be similar but genetically different from those causing disease in East Africa and the Caribbean region (Harrison *et al*. 1994; Tymon *et al.* 1997);
- LYD strains in Ghana and Nigeria were found to be genetically identical, but different to the LYD strains in East Africa (Tymon *et al.* 1997);
- Phytoplasma strains responsible for the disease in Kenya and Tanzania were found to be identical, but the isolate from Mozambique was different, and was more related to the isolates from West Africa (Mpunami 1997; Mpunami *et al*. 1999); and
- MARI's biotechnology capacity further enhanced through improved laboratory facilities, PhD training of a pathologist and short-term training of technicians in molecular biology techniques.

Biotechnology improvement of coconut: Application of DNA marker technology to germplasm characterization and breeding (1997 – 2001)

The general objective of this research was to develop and use DNA marker technology for the evaluation of biodiversity in coconut germplasm and to assist breeding. It was funded by the EU under the International Cooperation with Developing Countries (INCO-DC) programme from 1997-2001, in addition to the support from MARI, MPIPB, Germany, NEIKER, Spain and the PCA, the Philippines. The major activities included:

- Establishment of mapping population;
- Further development of the coconut linkage map;
- Quantitative trait loci (QTL) analysis of the mapping population; and
- Enhancement of MARI's biotechnology capacity through provision of laboratory facilities and short-term training of local researchers and technicians in molecular biology techniques.

Evaluation of the performance of hybrids and high-yielding varieties, and farmers' varietal preferences

Tanzania is one of the 18 countries which participated in a survey to assess the performance of high-yielding coconut varieties grown by farmers and larger holdings. This project was funded by IPGRI/COGENT, the Asian and Pacific Coconut Community (APCC) and the BUROTROP. The survey confirmed that the local East African Tall is the predominant and most preferred coconut population in Tanzania. However, improved hybrids with high yield potential proved to be more susceptible to drought conditions caused by insufficient and unfavourable rainfall distribution. This has discouraged framers from planting hybrids. The findings of the survey have been published by APCC.

Improving the small–scale extraction of coconut oil

The NCDP collaborated with NRI, UK, and other institutions from Ghana, Côte d'Ivoire, and India in a CFC-funded project aimed at developing improved and appropriate small to medium-scale coconut oil processing technologies. The main results of the project activities in Tanzania included the:

- Development and use of a hand-operated rotary coconut grater, which is more efficient in terms of oil extraction (up to 20% more oil because the gratings are finer, Mpagalile *et al.*1998; Swetman *et al.* 1998) and require less time for grating compared to the traditional single bladed grating tool; and
- Use of ram and screw (or bridge) press which improved oil extraction efficiency and was beneficial to small-scale, village-based oil processing women groups.

Other ongoing projects

National Coconut Development Programme (NCDP)

The purpose of the NCDP since its inception in 1979/80 is to improve coconut production and utilization in Tanzania through a number of R&D interventions. The NCDP is funded mainly by the Government of the Federal Republic of Germany (FRG) through the Germany Agency for Technical Cooperation (GTZ) and by the Government of Tanzania using its own resources and a loan from the World Bank. The project is planned to last for 26 years, and is being implemented in phases. The specific objectives of the Phase VIII of the project (2001-2004) are:

- To consolidate the breeding activities for improved, high yielding, disease resistant and drought tolerant coconut varieties;
- To develop and disseminate integrated crop protection measures for economically important coconut pests and diseases;
- To establish appropriate agronomic and socioeconomic requirements of viable coconut-based farming systems and provide recommendations to farmers; and
- To improve research-extension-farmer linkages on coconut production and processing.

Research results obtained as of 2004 can be summarized as follows:

- Lethal disease (LD), which has been confirmed to be caused by phytoplasma, appears to be more severe in the southern coastal belt than in the northern part (Schuiling and Mpunami 1990; Schuiling *et al*. 1992). An impact study showed that the disease had serious negative impacts on economic, socio-cultural and environmental effects in coconut-based farming systems. The use of molecular techniques has led to a better understanding of the aetiology and epidemiology of the disease as well as the genetic relationships between and within different coconut populations. Further collaborative efforts in LD research, including the identification of molecular markers associated with LD resistance, are necessary.
- With regard to breeding for improved planting materials with good resistance to LD, there has not been any breakthrough as yet. Progenies obtained by crossing individual palms of different varieties that had survived the disease for more than 12 years have also succumbed to lethal disease under heavy disease pressure. However, there are indications that resistance might be found within some of the local East African Tall sub-populations especially for areas with low- to medium-disease pressure.
- Dwarf (D) varieties continued to be more susceptible to drought than Tall (T) varieties. All imported Dwarf, Tall, D x T, T x D and T x T also proved to be more susceptible to drought than the local coconut population. These differences are due to morpho-physiological differences in terms of rooting systems, epicutical wax content and stomata regulation especially during the dry period.
- An effective Integrated Pest Management (IPM) package for the control of *Pseudotheraptus wayi,* using the African red weaver ants (*Oecophylla longinoda*) as a biological natural enemy, has been developed and is now being disseminated to more coconut farmers. The package includes intercropping coconuts with host plants of *O. longinoda* (e.g. citrus) to enhance its establishment in the field, the use of a chemical bait (Amdro) to control the antagonistic ant *Pheidole megacephalla*, which is a natural enemy of the red weaver ants; and facilitating the spread of the weaver ants in the field by interconnecting palms using simple ropes.
- Economic analyses of different coconut-based farming models revealed that intercropping of coconuts under wider spacing (10m within and 15m between the rows) with sweet potato or cassava gave the highest economic returns and benefit-cost ratio (Mwinjaka 2000). Cassava is preferred as an intercrop for coco-

nuts because of its relatively stable yields and its growing demand in urban markets. However, the areas cultivated for these inter crops are normally small because both are labour demanding; while the potential labour supply per household is limited to 2 - 3 people.

- Simple but more efficient small-scale processing technologies (e.g. manually operated rotary graters and ram press) have been developed and disseminated to coconut farmers.
- Impact studies conducted over the years have revealed that the project has been able to reverse the declining production and improve farm productivity. The area under coconuts has been increasing at an annual rate of 2%, yields have increased from 23-25 nuts/palm/year in 1980s to 30-40 to 2004 due to the fact that more farmers are applying improved crop management practices.

Construction and exploitation of high density DNA marker and physical maps in the perennial tropical oil crops coconut and oil palm: from biotechnology towards markers-assisted breeding (LINK2PALM)

This is a three-year project that started in August 2001 with financial support from the EU under the INCO-DEV programme. The institutions collaborating in this project as full partners include Max Planck Institute for Plant Breeding - Germany as the coordinator, PCA, NEIKER - Spain, CIRAD, France, the Malaysia Palm Oil Board (MPOB), Marc Delorme Coconut Station - Côte d'Ivoire, Indonesian Oil Palm Research Institute (IOPRI) and SOCFIN Indonesia. MARI and CICY of Mexico are participating as sub-contractors to MPIZ. Its main objectives are:

- To provide the methodological basis and molecular tools for improving the breeding efficiency in two perennial tropical oil crops (coconut and oil palm);
- To develop DNA marker-based breeding strategies in collaboration with the most important countries in coconut and oil palm production, and to directly transfer to developing countries small-scale technological solutions for the genetic improvement of these two tropical oil crops;
- To perform QTL analysis of the mapping populations; and
- To disseminate the developed molecular marker technology through training, workshops and laboratory courses.

Capacity building

Technical assistance /expert advice

In 1998, COGENT sponsored an expert from Côte d'Ivoire to visit 10 different coconut producing countries in Africa, including Tanzania, to identify the coconut R&D needs of these countries and integrate these in the formulation of an African and Indian Ocean coconut regional project proposal. The proposal was further refined by incorporating the recommendations of the 2nd International Coconut Workshop held in Mombasa, Kenya in May 2000. This project was implemented as a CFC-funded project (2000-2004).

Training and human resources development

From 1997 to 2002, four Tanzanian coconut researchers underwent staff development training on COGENT's standardized coconut breeding techniques (STANTECH), embryo culture techniques and on the use of the microsatellite kit and dedicated statistical software.

COGENT meetings/workshops

In 2001, Tanzania hosted the 2nd CFC-funded Project Workshop/ Consultations on 11 to 12 June 2001, followed by the 10th COGENT Steering Committee Meeting from 12 to 15 June. A participant from MARI also attended the following:

- Project Inception and Stakeholders' Meeting on 'Poverty Reduction in Coconut growing communities', 25 February – 1 March 2002, Ho Chi Minh City, Vietnam;
- Midterm evaluation meeting for the 'International multi-location coconut hybrid trials', 25 – 27 July 2002 in Kingston, Jamaica; and
- Project meeting on 'Overcoming poverty in coconut growing communities' in Hat Yai, Thailand on 9 – 13 May 2005.

Financial support and funding

As far as funding support for projects initiated by COGENT in Tanzania is concerned, CFC and DFID have so far provided a total of US$ 41 333, while counterpart financing from the Government of Tanzania amounts to US$ 39 083.

From 1990 to date, Tanzania also spent about US$ 8M from its own sources and a loan from the World Bank, US$ 7.5M from the Government of the Federal Republic of Germany (FRG) and about US$ 631 500 from the EU and CFC.

A summary of capacity building activities and projects in Tanzania from 1990-2003 is given in Table 2.

Table 2. COGENT – Tanzania capacity building and projects factsheet

1. Capacity building

a) Technical assistance provided by COGENT to Tanzania

Expert	*Dates*	*Purpose*
P Y N'Cho	Mar 1998	To identify research and development needs and to formulate an Africa/Indian Ocean coconut regional project proposal

b) Local researchers trained in other countries

Name	*Dates / Country*	*Training Course*
Linus Issay Isaac Masumbuko	16 – 26 Jun 1997, Côte d'Ivoire	Regional STANTECH Trainers' Course for Africa
Kennedy Mkumbo	27 – 31 Oct 1997, Philippines	Embryo Culture Workshop/Training
Raphael Sallu Emmarold Mneney	16th to 28th May 2002, France	Workshop on Coconut Genetic Resources Management Using Microsatellite Kit and Dedicated Statistical Software

c) IPGRI-COGENT meetings/workshops held in Tanzania

Date	*Activity*	*Location*
11-12 June 2001	CFC project workshop	Dar es Salaam, Tanzania
13-15 June 2001	10th COGENT Steering Committee meeting	Dar es Salaam, Tanzania

2. Coconut Research Projects in Tanzania from 1990 -2003

Project Title	*Expenditure (US$)*	*External Funding Agency*	*Budget/ National Funding (US$)*	*Status*
National Coconut Development Programme (for 2000 – 2004)	7 500 000	FRG	8 000 000	Ongoing
International Multi-location Variety Trials to identify suitable hybrids and varieties for Africa, Latin America and the Caribbean (MLVT) (1998-2004)	34 833	CFC	33 333	Ongoing
Improvement of *in vitro* techniques for collecting and exchange of coconut germplasm	5000	DFID	5000	Completed
Establishing a framework and selecting project sites for a nationwide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Tanzania	1500	DFID	750	Completed
Construction and exploitation of high-density DNA marker and physical maps in the perennial tropical oil crops coconut and oil palm: from biotechnology towards marker-assisted breeding (LINK2PALM) (2001-2004)	7500	EU		Ongoing
Biotechnology improvement of coconut: Application to Breeding and Crop Protection (1994 – 1997)	98 000	EU		Completed
Biotechnology Improvement of Coconut: Application of DNA Marker Technology to Germplasm Characterization and Breeding (1997 – 2001)	134 500	EU		Completed
Sustainable coconut based-farming systems: Operational and economic analysis models (1992- 1998)	89 000	EU		Completed
Investigation into the aetiology and control of lethal yellowing type-diseases (1992- 1998)	200 000	EU		Completed
Improving the small–scale extraction of coconut oil	80 000	CFC		Completed
TOTAL	**8 150 333**		**8 039 083**	

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Africa and Indian Ocean

Status of coconut genetic resources research in Kenya

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Introduction

Coconut (*Cocos nucifera* L.) was introduced to Kenya in the 16th century by the Portuguese. Its cultivation spread rapidly and became a crop of considerable economic importance. Arab traders and white settlers grew the crop in large plantations until the end of the 19th century when production and marketing shifted to small-scale farmers. Today, coconut is mainly a small-scale farmer's crop, with over 80% of coastal farm households deriving their livelihood, either directly or indirectly, from coconut.

In 1966, there was an estimated two million coconut trees planted in Kenya as compared to 456 636 trees existing in 1914. Surveys indicated that this might have risen to as many as 2.5 million trees in 1977 (Eijnatten 1977). Current estimates put the total number of palms at about 4.4 million. Ironically, the increase in the number of trees was not accompanied by an increase in yield. The average yield of nuts has been estimated at 1.5 t/ ha, though actual recorded yields of copra are as low as 0.45 t/ha. Fruit component analysis done for some Mtwapa palms showed an average fresh copra yield of 233g per nut (104 g of dry copra/ nut assuming 50% moisture content). Most of the coconut palms are planted in dense clusters of 10-200 palms around homesteads of less than 0.5 ha (Sculling and Mpunami 1991). Except for one large plantation at Msambweni in Kwale district, there are no large coconut plantations in Kenya.

Research activities and outputs

Yield records of selected coconut palms

Research attempts have been made to improve coconut production in the country. Three types of coconut palms have been described: the East African Tall (EAT), Dwarf types and hybrids. EAT is most common along the East African coast. EAT yields nuts with good quality copra and toddy but their coconut water is not as good as that of Dwarf coconut

(Gethi and Malinga 1997). Selection of high-yielding mother palms of EAT was done in Mtwapa from 1966 to 1967. Twelve trees with ages varying between 15 and 25 years were selected and further yield recording was continued from 1979 to 1980. Data gathered indicated that yields ranged between 18 and 128 nuts per palm. Tree X-128 gave consistently high yields of over 100 nuts. It was used to raise seedlings in the nursery.

Observations on Dwarf x Tall hybrids

Generally, the Dwarf types produce excellent immature nuts (for use as tendernut) but little copra. The hybrid palms are usually crosses between the EAT and introductions from West Africa and Malaysia. Thirty-five Dwarf x Tall hybrids were imported from the Côte d'Ivoire and established at Mtwapa (20 hybrids) and Msabaha (15 hybrids) in 1978. They performed dismally and have since died because of lethal bole rot. Attempts were made to identify Dwarf palms from different areas along the coast to provide nuts for use in a hybridization programme. Seventy palms were identified in the area between Mtwapa and Kilifi town.

Studies on germination period of Tall and Dwarf coconuts

Germination time of Tall and Dwarf coconut was studied (Eijnatten 1980). The study showed that the most important period of germination of the two types of coconut was within four months from time of planting. The best month to establish seednuts was in October for them to germinate in January and the seedlings would be ready for planting by April.

Coconut fertilizer experiments

Fertilizer trials were set up at Mtwapa and Matuga. Most of them were abandoned due to plant variability and poor yields (Eijnatten 1979). However, preliminary trials indicated that fertilized palms yielded more especially when nitrogen was applied. In 1979, a fertilizer experiment was set up to study the influence of NPK on the productivity of mature Tall coconuts and to observe the influence of normal weed control (regular slashing) of natural vegetation, ring weeding and mulching in a grassed coconut plantation. No significant difference was noted among the treatments. Coconut palms are known to respond slowly to application of fertilizer. Nevertheless, the overall yield levels were low which may be due to severe coreid bug attack (Omondi and Eijnatten 1980).

Survey on coconut diseases in coastal Kenya

Surveys done on lethal yellowing in Kenya have shown that palms found in the country were relatively free of this disease. Sculling and Mpunami (1991) suggested that selections could be made in Kenyan genotypes in search of resistance to lethal yellowing. Long-term preventive solution to this problem lies in the introduction of resistant varieties and strict quarantine of seeds imported from lethal yellowing-infected countries or regions.

The Second International Coconut Workshop for Africa

The Second International Coconut Workshop for Africa was held in Mombasa, Kenya from 8 to 12 May 2000. The theme of the workshop revolved around finding ways to help African coconut farmers in the 21st century. It was recommended that Kenya and Tanzania lead the work on combating Rhinoceros beetle, *Oryctes monoceros,* in the region. The following strategies were proposed to help Kenyan farmers to revive the coconut industry: (1) produce high-value products from parts of the coconut that are normally thrown away (husk, shell, water and wood); (2) plant high yielding and adapted varieties; and (3) intercrop coconut with high-value crops.

Diagnostic survey of the coconut industry in Kenya

In 2000, a survey was conducted to establish the status of the coconut industry in Kenya (Muniu *et al.* 2000). It was found out that coconut was ranked the most important perennial crop in Kilifi District. Peak harvest period was determined to be in January. Yield of immature nuts was 50 nuts/year while yield of mature nuts was 100-200 nuts/year. On an average, farmers tapped 10-20 palms, yielding about 1-4 litres of toddy per day. Marketed products included immature nuts, copra, coconut leaves, brooms and toddy. The survey also revealed that the most significant constraints to the development of the Kenyan coconut industry were market-related, particularly the lack of reliable and rewarding markets, marketing (transport) and pricing. Unreliable market structures and low prices for most available products were quite prominent. Lack of processing knowledge and processing capacity was also noted as a major shortcoming in deriving maximum benefits from the many opportunities available to the coconut industry. Low yields were also common particularly in the dry zones, as well as aged (senile) and poorly-managed trees. The genetic base of the Kenyan coconut was also noted a narrow and limited to East African Tall varieties. Farmers expressed the need to widen the range of varieties available to them for planting. It was also determined that the Rhinoceros beetle was the major pest of coconut in the region, including mites and termites.

The absence of farmer organizations dealing with coconut production and marketing, as well as the lack of a national policy to support production, processing, marketing and utilization of coconut products hinders the development of the coconut industry in Kenya.

Generating income from coconut products in the coastal areas of Kenya

With coordination from the International Coconut Genetic Resources Network (COGENT), a Kenyan coconut scientist was sent to Vietnam and Thailand in June 2003 to observe and learn the various technologies for processing and utilizing coconut products. Upon return, the scientist implemented a project aimed at promoting the production, processing, and marketing of coconut products and by-products. Currently, a pilot workshop for making products from coconut shell, husk and wood has been established. The workshop is equipped with machine and tools mostly acquired from Vietnam such as a decorticating machine, beating machine, one- and two-ply rope-making equipment and doormat-making equipment. Various value-added coconut products from shell such as bangles, hair clips, lampshades cups, buttons and belts have already been made. Over 20 community-based organizations have been identified and scheduled for training on the various value-adding processing technologies to scale up the project.

Suggested next steps

Institutions

The government should form a national body mandated to address research and development issues in coconut. This national body should prepare action plans and proposals aimed at addressing the identified constraints and opportunities to improve the country's coconut industry.

Coconut farmers should also form associations and federate these so that they can address and air their concerns to relevant stakeholders and/or policy makers.

Conservation of coconut genetic resources

The research institute mandated to carry out research on coconut should undertake the following activities aimed at conserving and sustaining coconut genetic diversity in Kenya:

- Establish a national coconut genebank;
- Promote the collecting, conservation and exchange of disease-free germplasm in collaboration with COGENT's International Coconut Genebank for Africa and Indian Ocean (ICG-AIO);
- Promote coconut–based farming systems and the production and use of high-value products so that the coconut germplasm is conserved and used; and

- Screen for resistance against lethal yellowing-like diseases and for tolerance to drought and other biotic and abiotic stresses.

Control of pests and diseases

The research institute should collaborate with other coconut R&D organizations in other countries to investigate the epidemiology, etiology and control of lethal yellowing disease.

The research institute should also evaluate, adapt and/or develop effective methods to control the spread and damage caused by Rhinoceros beetle, coconut mites and termites, and other pests.

Crop management

Develop coconut-based farming system research projects and collaborate with other countries where common problems in this area exist.

Coconut product utilization

Develop technologies to maximize the utilization of and generate additional income from the different parts of the coconut (such as the husk, shell, water, wood and sap) other than copra.

International collaboration

Kenya should continue to be an active member of COGENT and endeavour to become a member of other international coconut development organizations like the Bureau for the Development of Research of Tropical Perennial Oil Crops (BUROTROP) and the African Oil Palm Development Association (AFOPDA).

Information

The research body to be established should link with various information services within and outside the country in order to acquire necessary information on coconut.

Funding

A mechanism should be established to raise funds for coconut development. Possible methods include a levy on imported vegetable oils such as that imposed on sugar as well as a levy on locally-produced coconut products. International donors should also be tapped to fund coconut R&D projects.

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Africa and Indian Ocean

Status of coconut genetic resources research in Mozambique

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Introduction

Coconut in Mozambique is mostly grown along the coast with an estimated production area of 16 000 ha. Coconut production is mainly a family based enterprise with more than 60% of the stands located in small landholdings. It is estimated that about 14% of the Mozambican population depends on the crop as their main source of income and nutrition or food. The country's total production is about 60 000 tonnes of copra-equivalent, of which 50% is consumed locally. Revenue from coconut exports is about US$ 10 million annually.

Coconut production in Mozambique is mainly affected by the following:

- Lack of improved germplasm;
- High incidence of pests and disease, particularly the Lethal Yellowing Disease (LYD) which is presently devastating the industry; and
- Lack of research capabilities, both human and infrastructure.

The extent of coconut germplasm diversity in Mozambique has not yet been fully investigated. Most of the local cultivars are of Tall types that fall under the general category of Mozambican Tall. Therefore, there is an urgent need to characterize and conserve the country's local germplasm.

Some germplasm were introduced into the country in the early 1980's by the Madal Company in Zambezia Province. Some of the introduced varieties included Brazilian Green Dwarf, Brazilian Yellow Dwarf, Malaysian Red Dwarf and Malaysian Yellow Dwarf. These materials were used in the production of hybrids by the Madal Company, primarily for new plantings and rehabilitation of old stands.

Coconut genetic resources research and development activities

Unfortunately, Mozambique has yet to have a national coconut research programme. However, with support from the International Coconut

Genetic Resources Network (COGENT), the country has benefited from collaborative activities that included:

1. **Capacity building**
   a. Participation of one Mozambican coconut researcher in the Regional STANTECH (Standardized research techniques in coconut breeding) Trainer's Course for Africa, which was held in Côte d'Ivoire from 16-26 June 1997;
   b. Participation of a coconut researcher to another training course on Standardized Research Techniques in Coconut Breeding which was held from 20-28 January 1998 in Côte d'Ivoire;
   c. Technical assistance to identify research and developments needs and to formulate an Africa-Indian Ocean coconut regional project proposal (March 1998); and
   d. Technical assistance to establish the multilocational trial project (5-12 November 2002).
2. **Project awareness**
   Dr Pons Batugal, COGENT Coordinator, visited the country in 2002 to discuss with concerned government officials the importance of collaboration between the country and COGENT in developing the coconut genetic resources of Mozambique.
3. **Varietal trial**
   Through coordination of COGENT, an evaluation trial was conducted to identify suitable coconut hybrids/varieties for Mozambique. The project is being implemented by Grupo Madal and funded by the Portuguese Government.

Other activities

1. In view of the severity of LYD in the northern and central parts of the country, a national contingency strategy was developed in 2000. Among its more significant activities included controlling the movement of coconut plants from the affected zones and raising awareness among coconut growers on LYD;
2. Conduct of workshops on LYD which were held in Zambezia and Cabo Delgado Provinces;
3. Mapping and monitoring of LYD movement in the country, which were carried out with support from the Centre Institut de Recherche Agronomique pour le Développement (CIRAD) of France;
4. Establishment of a French Development Agency-funded project to increase coconut production in small coconut landholdings in Zambezia Province. The project components include:
   - Implementation of an LYD programme;
   - Intensification of production programme in the areas not yet af-

fected by the LYD;
- Dissemination of improved drying techniques for copra;
- Development of related training programmes at local and national levels; and
- Elaboration of the coconut development master plan.

Projects in progress

1. The National Agronomic Research Institute (NARI) is in the process of establishing a national coconut research programme and COGENT has been requested to assist in this process, specifically for training and capacity-building;
2. With support from COGENT, the project on "Poverty Reduction in Poor Coconut Growing Communities in Mozambique" has been designed and submitted to relevant donors for funding;
3. Development of a Mozambique coconut genebank to address LYD; and
4. Procurement and development of LYD-resistant, high-yielding and high-value coconut varieties with technical support from COGENT.

Africa and Indian Ocean

Status of coconut genetic resources research in Seychelles

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Introduction

Scientific research on coconut had its heyday in Seychelles when the export of copra was the mainstay of the economy until the tourism boom in the early 1970s. Thereafter, research focused on the selection of better performing varieties that are well adapted to the poor granitic soils and which showed positive response to fertilizers and other inputs.

Most of the coconuts planted in the country are local Talls. These Talls are made up of a number of different varieties characterized by different nut sizes, shapes and productivity but with no apparent differences in tree morphology. Among the common local varieties planted are Coco Raisin, Coco le Haut, Coco le Rein and Coco Bleu.

In a bid to boost coconut production, Seychelles imported some 10 000 nuts from Ceylon (now Sri Lanka) during 1906 -1911. Studies conducted in 1935 found that these imported varieties were inferior to the local Talls as they required far more intensive cultural practices and were more prone to diseases. In 1931, Dwarf coconuts were introduced from the Malay States, particularly the Malayan Yellow and Malayan Red Dwarfs (MYD and MRD). Fruits of these varieties are mostly used for decorative purposes and consumed locally or sold to tourists as tendernuts for drinking.

Alternative uses of the coconut

In 1994, Pakistan, the last remaining importer of coconut and copra from Seychelles at that time, ceased coconut-related transactions with the country. This spelled doom for most coconut farmers and growers in Seychelles who depended solely on the crop and did not have alternative sources of income. Since then, national coconut research priority has shifted to “finding new uses for an old product”.

There are hundreds of known and documented uses for the coconut. Although the Tree of Life finds many uses in the everyday life of the Seychellois, there is an urgent need to look at some of these products as potential income earners. To this end, the Ministry of International Business (MIB), in collaboration with the Ministry of Agriculture and

Marine Resources (MAMR), organized a one-day workshop in March 2002 to review the situation of the coconut industry in the country and to propose strategies to rehabilitate it. The workshop was attended by major stakeholders from both the private and public sectors of the coconut industry. Dr Pons Batugal, International Coconut Genetic Resources Network (COGENT) Coordinator, also attended, enlightening the participants on the scientific and technical aspects of the coconut industry. Some of the more economically feasible products for Seychelles which were identified included:

1. **Palm heart**. In August 1972, a consignment of palm hearts was sent to London whereby excellent prices were obtained. Recent market surveys conducted by MAMR revealed that palm heart is in high demand by both locals and tourists in the country. To maximize the production of palm heart, the MAMR has set up small, high density plantations for studies and trials for the production of palm heart. The trials recommended a spacing of 2.5 m x 2.5 m and a harvesting period of three years after planting. Early cropping results in better control of major pests particularly the melittomma larvae and the Rhinoceros beetle. It also relieves the pressure on endemic palms that are also in demand for palm heart and are sometimes poached illegally. All indications point that this delicacy could be a lucrative foreign exchange earner for Seychelles.
2. **Tendernuts.** This yet untapped product holds great market potential in the country as both locals and tourists usually prefer such a healthy and tasty thirst quencher over commercial carbonated drinks.
3. **Coconut milk/cream**. Most Seychellois cuisine use coconut as a main ingredient, particularly in the form of milk or cream. In the late 1980s, the government, in partnership with a French company, established a factory that produces coconut cream in commercial quantities. The venture was plagued by several problems, including equipment operation, the type of packaging material used and, to a lesser extent, the inconsistent supply of raw material. Though public response was good, the factory closed down due to the problems mentioned.
4. **Coconut cake and oil**. Traditionally, every Seychellois home raised local poultry for home consumption, which were predominantly fed with coconut cake. On a more commercial scale, the Animal Feed Factory of the Seychelles Marketing Board produces several livestock feed formulation which contained a reasonable amount of coconut cake. Oil produced could easily be absorbed

by the local soap industry to replace the present imported coconut oil. In 2000, imports of coconut-based products amounted to SR 610 565 (US$ 119 719), while in 2001 the amount decreased to about SR 458 558 (US$ 89 913).

5. **Agro-processed products**. Coconut-based confectionery and other processed products could certainly replace some of the imported materials used in agroindustries.
6. **Craft items**. With the recent ban by government on importation of craft items for resale, it is envisioned that the use of local coconut raw material will gain impetus.

Pests and diseases

An important aspect of coconut research identified in the country is in the area of pests and diseases. Although very few coconut diseases exist in Seychelles, some of them do significant damage to the coconut industry.

The melittomma borer (*Melittomma insulare*) is by far the most significant pest of economic importance in coconut in Seychelles. A traditional method of controlling this pest involves gouging the base of all bearing trees and applying a solution of tar and creosote.

Another major pest is the Rhinoceros beetle (*Oryctes monoceros*) which attacks the base and the growing point of the crop. Various control trials have been undertaken and tested since the 1900s. In 1971, a virus (*Rhabdionvirus oryctes)* was tested as a biological control agent against the Rhinoceros beetle. Although field trials gave encouraging results, the technology still needs to be further refined and disseminated.

Rats (*Rattus rattus)* are an ever present threat to coconut production. Mealy bugs (*Pseudocous adonidum*) and scale insects are also present in the country but are not considered as economic pests.

Future research considerations

Whatever coconut R&D developments take place in the country in future, the following basic and inherent factors shall be taken into considerations:

Land. With the rapid rate of social development and competition for land by other economic sectors such as tourism and manufacturing, there is less and less land available for agriculture. Thus, future coconut plantations may have to be of lesser acreage, planted more densely or managed in complementation with another purpose (e.g. lending aesthetic value to eco-tourism centres).

Labour. The present cost of labour will greatly affect the price of the alternative high-value products from coconut. In the short run, such products may not be economically competitive with imported products but in the long run this would translate to greater foreign exchange savings for the country. Therefore, there is a need to train and build-up the capacity of farmers and growers and/or their families in producing high-value coconut-based products so that they could compete with their foreign counterparts.

Varietal selection. Additional technical research work and training would be needed to match varieties with intended uses. It may be noted that some varieties may produce better drinking nuts whereas others, better palm heart. With the help of COGENT and the CNRA Marc Delorme Station in Côte d'Ivoire, Seychelles obtained 50 seednuts of Brazilian Green Dwarf, a highly priced variety for tendernuts. If suitable, this variety will be propagated for wider plantings.

Education and awareness. Potential investors must be educated and be made aware of business opportunities that exist in the country and elsewhere in the world. Studies must be undertaken to understand the true nature and trends in the demand for the various coconut-based products and their derivatives.

Capital and technology. Any commercial-scale processing of any part of the coconut would require significant initial capital investment. Commercial production in Seychelles will be limited by its relatively small domestic market. The technology chosen to process any added-value coconut product must consider the issues of the market as well as availability of a constant supply of raw materials.

The future of the coconut industry in Seychelles will depend largely on sharp and innovative businessmen, a national policy to support the industry, and sound technical skills and knowledge in coconut production and coconut processing on the part of producers and growers.

Latin America and the Caribbean

Status of coconut genetic resources research in Brazil

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Introduction

Coconut growing is important for the economies of Northeastern and Northern Brazil, accounting for approximately 82% of the country's production (IBGE 2003). Brazil ranks fifth among the coconut producing countries in the world (FAO 2002). Coconuts are planted from the Northern State of Roraima to the State of Paraná in the South, with high concentrations in the coastal line from Pará to Rio de Janeiro. They are cultivated in the most diverse soil, climate and management conditions. The most utilized coconut parts are water from the green coconut (tendernut) and the fresh meat from the mature nut. The use of coconut by-products in Brazil is still very limited.

Populations of Tall coconut palms introduced by the Portuguese in the 16th century spread through the northeastern coastal zone, adapting themselves to different environmental conditions to create different ecotypes (Ribeiro *et al.* 1999; 2000). The Brazilian Agricultural Research Corporation (Embrapa) collected, characterized and conserved the genetic variability of these populations, and used them for developing superior hybrids with better production traits and quality, adapted to different Brazilian agroecological zones. Brazil has established a coconut genebank in the State of Sergipe to serve Embrapa´s coconut improvement programme. There is now a commitment to upgrade this genebank to become an International Coconut Genebank for Latin America and the Caribbean (ICG-LAC) with the support of the International Plant Genetic Resources Institute (IPGRI) and the International Coconut Genetic Resources Network (COGENT).

Coconut production constraints in Brazil

The following are the major limitations to coconut production in Brazil:

1. Use of unimproved, low-yielding varieties;
2. Ageing palm populations and inadequate management practices;
3. Occurrence of diseases and pests;
4. Adverse climatic conditions;

5. Rising cost of inputs and stagnation and/or declining prices of produce;
6. Underutilization of the crop and limited diversity of products; and
7. Unstable markets for coconut and coconut products.

Coconut genetic resources in Brazil

Germplasm introduction

According to Siqueira *et al.* (2002), coconut was first introduced by the Portuguese in 1553, in Bahia, from seeds of Tall coconuts originating from Cabo Verde Island. A second introduction happened in 1939, in Rio de Janeiro coastal area. A third was carried out by the Cocoa Authority (CEPLAC) in 1978, again in Bahia, introducing the West African Tall (WAT) from Côte d'Ivoire; in partnership with the Centre Institut Recherche Agronomique pour le Développement (CIRAD). A fourth introduction occurred in 1981, when Sococo, a coconut processing company, imported seednuts of West African Tall (WAT), for planting in a field in the state of Pará. A fifth introduction happened in 1983 by Embrapa, with ecotypes from Côte d'Ivoire, which initiated the establishment of the national coconut genebank in Neopolis-SE. The populations introduced include WAT, Rennell Island Tall (RIT), Polynesian Tall (PYT), Rotuma Tall (RTT), Tonga Tall (TONT), Vanuatu (VTT) and Malaysian Tall (MLT) (Siqueira and França-Dantas 1984). Populations of WAT, RIT, TONT, VTT and MLT were reintroduced in 1984, while those of RIT, PYT and of VTT were reintroduced in 1986 (Ribeiro and Siqueira 1995).

Dwarf types were first introduced in 1925, with seedlings procured from India and distributed in Bahia, Pernambuco and Rio de Janeiro (Siqueira *et al.* 2002). A second introduction of Dwarfs took place, in 1938 to Araruama and Cabo Frio, in the coastal area of Rio de Janeiro, with seedlings of the Yellow Nyor Gading, originated from Malaysia. In 1939, Rio de Janeiro was the site of the third introduction of varieties of Red and Green Dwarfs from Malaysia. In 1978, under an agreement between the Comissão do Plano de Recuperação da Lavoura Cacaueira (CEPLAC) and ex Institut de Recherche pour les Huiles en Oleagineux (IRHO), actually CIRAD, seeds of Malayan Yellow Dwarf (MYD) and Cameroon Red Dwarf (CRD) were imported and planted in Bahia. In 1981, the Sococo Company imported MYD seeds from Côte d'Ivoire and planted them in Para. A sixth introduction was by Embrapa in 1982, with varieties of MYD, MRD and CRD from Côte D'Ivoire, for the national genebank in Neopolis. Table 1 shows the list of introduced accessions in Embrapa's genebank in Neopolis-SE as of 2003.

Germplasm prospecting and collecting

As mentioned above, Embrapa's coconut germplasm research were activities initiated in 1982 with the introduction of Tall and Dwarf coconut palms from Côte d'Ivoire. At the same time, Embrapa initiated the prospecting and collecting of germplasm of existing populations in Brazil.

From 1982 to 1995, Tall populations were identified and characterized as legitimate and homogeneous populations at the following: Praia do Forte - BA, Pacatuba – SE, Merepe and Santa Rita – PE, São José de Mipibu, Baia Formosa and Georgino Avelino - RN. In relation to Dwarf varieties, the following populations were identified, collected and characterized between 1982 and 1983: Brazil Green Dwarf (BGD), Jiqui (RN), Brazil Yellow Dwarf (BYD), Brazil Red Dwarf (BRD) and Gramame (Table 2).

Several populations of Tall and Dwarf also had been identified from other regions of the country but this effort had to cease due to lack of funds.

Embrapa's Coconut Genebank

Embrapa's Coconut Genebank is located in the Experimental Station of Betume, Neópolis, Sergipe-SE (10°25′22″ S and 36°34′31″ W at an altitude of 28 m). The terrain is coastal tableland type and the climate is characterized by tropical rainy with dry summers (Köppen classification), with rainfall, temperature and relative humidity average of 1200 mm, 25ºC and 70%, respectively. The soil is a Neossolo Quartzorênico (Brazilian classification) or Ustic Quartzipsamment (American classification).

There are 19 accessions, with 13 Tall and 6 Dwarf types, totaling 3379 palms in the genebank as of 2003 (Tables 1 and 2).

Due to adverse soil conditions at the experimental station, Embrapa decided to transfer the collection to the experimental station in Itaporanga-SE in 2000, next to the capital city of Aracaju where Embrapa Coastal Tablelands is located. This area is free of the predominant disease of the coconut palm in Brazil, the 'leaf rust', caused by *Botryodiplodia theobromae*. The new coconut genebank will have a total working area of 15 ha when the transfer is completed.

Table 1. Introduced accessions conserved in the Coconut Genebank of Embrapa as of 2003

Accessions	Country of origin	Number of palms
Tall types		
West African Tall (WAT)	Côte d'Ivoire	218
Rennell Islands Tall (RIT)	Rennell Islands – Solomon Islands	94
Polynesian Tall (PYT)	Tahiti	207
Rotuman Tall (RTMT)	Fiji	94
Tonga Tall (TONT)	Tonga	93
Vanuatu Tall (VTT)	Vanuatu	35
Malayan Tall (MLT)	Malaysia	34
Dwarf types		
Malayan Yellow Dwarf (MYD)	Malaysia	157
Malayan Red Dwarf (MRD)	Malaysia	204
Cameroon Red Dwarf (CRD)	Cameroon	154

Table 2. Local germplasm accessions conserved in Embrapa's genebank as of 2003

Accessions	Origin	Number of palms
Tall types		
Brazilian Tall (BRT) - Praia do Forte (BRTPF)	Praia do Forte - Bahia	479
Brazilian Tall (BRT) - Merepe (BRTMe)	Merepe – Pernambuco	149
Brazilian Tall (BRT) - São José de Mipibu (BRTSJM)	São José de Mipibu – Rio Grande do Norte	150
Brazilian Tall (BRT) - Baía Formosa (BRTBF)	Baía Formosa – Rio Grande do Norte	102
Brazilian Tall (BRT) - Santa Rita (BRTSR)	Santa Rita – Pernambuco	102
Brazilian Tall (BRT) - Pacatuba (BRTPc)	Pacatuba - Sergipe	102
Dwarf types		
Brazilian Green Dwarf - Jiqui (BGDJ)	Jiqui – Rio Grande do Norte	340
Brazilian Red Dwarf - Gramame (BRDG)	Gramame – Paraíba	491
Brazilian Yellow Dwarf - Gramame (BYDG)	Gramame - Paraíba	174

Coconut research and development activities in Brazil

International Coconut Genebank for Latin American & the Caribbean (ICG-LAC)

In 1999, a FAO/IPGRI/COGENT mission conducted a pest risk assessment in Brazil with the view of establishing an International Coconut Genebank for the Latin America and the Caribbean region (ICG-LAC). A site adjacent to the capital city of Aracaju-SE was found to be suitable for the ICG-LAC as it was found to be free of any lethal disease or pests, not prone to earthquakes or typhoons, and easily accessible.

The ICG-LAC will have an area of 150 ha and will host some 200 coconut accessions. The Brazilian Government, through Embrapa, has committed to establish the ICG-LAC provided that stakeholders, particularly IPGRI-COGENT, would share the cost of its establishment and maintenance.

International multilocation variety trials

The Common Fund for Commodities (CFC) through IPGRI/COGENT provided technical and financial support for the project 'Coconut Germplasm Utilization and Conservation to Promote Sustainable Coconut Production'. A component of this project, multilocation trials of coconut hybrids, in which Brazil participated together with Mexico, Jamaica, Benin, Côte d'Ivoire and Tanzania, tested six hybrids produced in Côte d'Ivoire with 4–8 local hybrids. From the first batch of seeds received from Côte d'Ivoire, two varietal trials were initiated in September 2000. The first trial consisted of six treatments (three hybrids from Cote d'Ivoire, two local hybrids and one local variety) with seven plants per plot replicated five times. The second trial had 10 treatments (six hybrids from Côte d'Ivoire, three local hybrids and one local variety, Praia do Forte Tall), with four replications and five plants per plot. With the seedlings from the second and third batch of seeds, one trial with 10 treatments, five replications and 16 palms per plot was set in September 2003. All these trials are planted at the Itaporanga field station of Embrapa Coastal Tableland. The initial result of the 5-year trial showed that hybrids flowered in 2.5-3.0 years from planting.

Training supported by COGENT

- One researcher from Embrapa Coastal Tableland participated in a cryopreservation course in 2003.
- Two researchers from Embrapa/CENARGEN and Embrapa Coastal Tableland participate in staff development training on the use of the STANTECH (Standardized research technique in coconut breeding) Manual and on the use of the microsatellite kit (molecular marker) and dedicated statistical software in 2002.
- One researcher from Embrapa Coastal Tableland assisted in formulating the LAC coconut regional project proposal in 1997.

Main activities supported by Embrapa and other Brazilian stakeholders

Projects

1. Coconut Active Genebank (Embrapa)
2. Development of coconut palm suitable to different ecosystems of

Brazil (Embrapa)
3. Improvement of the scientific knowledge and development of technologies for the control of the predominant diseases of the coconut palm (Embrapa)
4. Production of hybrid seeds of coconut palm (National for Council Scientific and Technological Development or CNPq)
5. Morphologic, chemical and sensorial characterization of water and fresh meat of fruits of cultivated coconut palms (Bank of Northeastern Brazil)
6. Fast production of seedlings of Talls and hybrid through tissue culture (Bank of Northeastern Brazil)
7. Advances in technical-scientific knowledge for the production of seedlings of Dwarf coconut palms (State of Sergipe Research Foundation or FAP-SE)
8. Development and selection of suitable hybrids of coconut palm under the different ecosystems of Sergipe (FAP-SE)

Training courses and meetings/ workshops
1. Course on the Production of the Coconut Palm (national and annual)
2. National Symposium on Coconut Water, October 2001
3. Closed Courses on the Culture of the Coconut Palm for technical assistance companies of Brazil (annual since 2003)

Results/ outputs

National Coconut Genebank

Passport and characterization data of accessions in the Active Germplasm (or Bancos de Germoplasma - BAG), de Coco have been provided for the International Coconut Genetic Resources Database (CGRD). Four populations of Tall ecotypes - Baía Formosa-RN, Merepe-PE, Pacatuba-SE, São José de Mipibu-RN and Santa Rita-PE, were introduced into the national coconut genebank. Prospecting activities of coconut palm populations have been conducted in seven states of Northeastern Brazil to obtain additional data.

Use of RAPD markers in diversity study

The RAPD technique was shown to be adequate for differentiating the tested populations, which represented Tall ecotypes from BRT – Praia do Forte, WAT and RIT. Cluster analyses based on Euclidian distance among plants showed that WAT, BRT and RLT represented homogeneous and distinct populations of Tall coconuts. In terms of genetic distance, WAT and BRT were closer to each other than with RLT, and yet each of these populations was still distinct (Wadt *et al.* 1999).

Use of microsatellite markers for genetic variability analysis

The objectives of this study were to develop and characterize microsatellite markers for coconut and to analyze the genetic variability among and within 10 Tall and Dwarf coconut ecotypes conserved at Embrapa's coconut genebank. Cluster analysis, unweighted pair-group method analysis (UOGMA) was applied to three main groups: one containing the Dwarf ecotypes samples, one with the Pacific Tall samples, and a third group formed by the BRT and WAT ecotypes. Brazilian and Asian Dwarf ecotypes appeared to be closer to Pacific Tall ecotypes than they did to BRT ecotypes. These results corroborated the hypothesis of an Asian origin for the Dwarf variety. Despite the fact that the BRT ecotypes are not genetically and agronomically well characterized as the Pacific ecotypes, crosses between the Dwarf genotypes and BRT genotypes, which are genetically distant, could be basis for breeding programmes in order to obtain higher genetic gains (Moretzsohn *et al.* 2001).

Development of the coconut hybrids/varieties

Under irrigated conditions, Embrapa is developing hybrids from its genebank accessions. Genotypes of BGD, MYD and CRD were the most precocious; flowering within an average of 2.5 years, while the most delayed was MRD, which flowered after 2.9 years. The hybrids started to flower between 3 years (BYD x BRT; BRD x PYT; BRD x WAT), 3.1 years (BYD x PYT; BYD x WAT; BGD x BRT and BRD x BRT) and 3.2 years (BRD x RIT). The coefficient of genotypic determination for bloom was high (bp=0.96), indicating the possibility of success in the improvement for this characteristic.

The production of fruits from hybrids in the first year after the beginning of the bloom was high (73 fruits/plant/year), varying from 66 fruits/plant/year (BRD x BRT) to 87 fruits/plant/year (BGD x BRT). In the second year, after the beginning of the bloom, the production was very similar to the first year. There was no significant difference between the hybrids and the Dwarfs.

Average fresh meat production of the hybrids was 400 g/fruit, varying from 378 g/fruit (BGD x BRT) to 429 g/fruit (BRDG x RIT). The Dwarfs, on the other hand, varied from 214 g/fruit (BGD) to 290 g/fruit (BRD), which was lower than that of the hybrids. However, the Dwarfs presented high genetic variability for this trait, with different plants producing above 350 g/fruit, which is quite suitable to Brazilian coconut agroindustry. In addition, it was also found out that the fat content of fresh meat of Dwarfs was low, with the values per variety recorded as BGD (25.8%), CRD

(26.5%) and MRD (32.1%). These results indicate that the fresh meat of Dwarf coconuts is suitable for use and processing by light-food industries.

With regards to coconut water, the hybrids BGD x BRT (468.2 ml/fruit), BYD x BRT (471.0 ml/fruit) and BRD x BRT (392.3 ml/fruit) were higher in water content than their respective female parent, BGD (385.9 ml/fruit), BYD (348.5 ml/fruit) and BRD (382.0 ml/fruit).

All Dwarfs and hybrids are susceptible to mite infestation (*Aceria guerreronis*) and to leaf diseases caused by *Botryodiplodia theobromae*, *Sphaerodothis acrocomiae* and *Phyllachora torrendiella*.

In the State of Amapá, a region with high but well-distributed annual rainfall (>2000 mm), the BYD, BGD and CRD flower well at 1.7, 1.8 and 2.0 years, respectively. Hybrids BYD x BRT and BRD x BRT, on the other hand, flowered at 2.5 years; BGD x BRT at 2.6 years; and the giant BRT at 3.4 years.

In the regions with annual rainfall of only about 1200 mm and unevenly distributed as in the coastal state of Piauí, BRT, BGD, BGD x BRT, BYD x BRT and BRD x BRT started to produce in the second and third year after blooming, registering 17.2 and 44.8; 109.1 and 91.9; 68.5 and 76.0; 64.2 and 98.1; 92.7 and 75.8 fruits/plant/year, respectively.

The research activities described above are also being carried out under different agroecosystems in the states of Alagoas, Pernambuco, Rio Grande do Norte, Pará, Goiás, Mato Grosso, São Paulo, Minas Gerais, Espirito Santo, Paraná and Distrito Federal, being part of the National Net of Evaluation of Cultivars of Coconut Palm (RENAC). A second RENAC is being implemented with other cultivars in the states of Sergipe, Bahia, São Paulo, Paraná, Brasilia and, possibly Alagoas and Mato Grosso.

Future plans

The following would be undertaken by Embrapa in the near future to further develop the coconut genetic resources in Brazil:

1. Establish the International Coconut Genebank for Latin America and the Caribbean in Itaporanga-SE; and
2. Maintain the experiments of the international multilocation hybrids trial and disseminate their results.

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Latin America and the Caribbean

Status of coconut genetic resources research in Mexico

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Introduction

Mexico is the major coconut producing country in Latin America after Brazil with 168 000 ha planted to coconut.

Since 1998, coconut farmers in the Latin America and Caribbean (LAC) region have been facing serious problems that have diminished their incomes due to the low prices of copra and the decrease in the yield of old coconut palms. In Mexico, in the Gulf–Caribbean region, there are about 30 000 ha of the Atlantic Tall coconut whose average yields have fallen to 550 kg/ha due to the prevalence of Lethal Yellowing Disease (LYD). In the last 16 years, LYD has devastated around 17 000 ha of coconut stands in the country.

Coconut palms affected by LYD die within a couple of months after infection. The common symptoms showed by an LYD-infected palm are as follows:

1. Fruits fall prematurely, the ovaries miscarry and also fall;
2. Open inflorescences exhibit partial necrosis while developing ones (after nutfall) exhibit total necrosis;
3. Mature leaves yellow and then turn brown. They later dry completely and hang limp from the shaft of the palm; and
4. The youngest leaves in the middle of the crown also die and fall usually after the mature leaves fall off, leaving the tree bald and with a telephone pole appearance.

Generally, it takes only about six months from the onset of the disease until the tree dies and assumes the characteristic telephone pole appearance (Figure 1). Mortality rate is 100% for palms infected by the disease. At the moment, LYD is the most serious problem affecting not only Mexico but also Honduras, Guatemala, El Salvador and Belize in Latin America; Jamaica, Haiti, Dominican Republic and Trinidad-Tobago in the Caribbean, as well as Tanzania, Ghana and Mozambique in Africa. In some of these countries, it is suspected that the causal agent of the disease could be a different strain of the Mycoplasm-Type Organism (MTO), although this is yet to be proven. Due to its extensive and rapid

Figure 1. Atlantic Tall coconuts in South Mexico affected by LYD

spread, it is estimated that LYD would eventually infect and devastate about 500 000 ha of coconut stands in these 12 countries. Currently, cooperative efforts are underway among these countries to combat the disease and to develop coconut varieties which are resistant to LYD.

Coconut research activities

Mexico and Jamaica are currently carrying out combined efforts to develop technology to overcome LYD, which include projects on genetic improvement, microsatellite analysis, *in vitro* multiplication and seed production. So far, genetic improvement seems to be the most feasible and effective measure against LYD. This involves the evaluation, selection and recombination of coconut germplasm to identify resistant sources which could be used in breeding programmes for LYD-resistant varieties. Other significant coconut R&D projects in LAC are briefly described below.

Multilocation trials to identify suitable coconut hybrids and varieties for Africa, Latin America and the Caribbean

Starting from year 2000, Mexico, Brazil and Jamaica participated in this COGENT-supported project funded by Common Fund for Commodities (CFC) to evaluate two groups of coconut hybrids where six were common in the experiments of all participating countries and four are local hybrids or varieties. It is envisioned that results obtained may be applied in other coconut countries with similar environmental conditions. In case of Mexico, eight local hybrids were evaluated:

- Malayan Red Dwarf x Panama Tall Aguadulce(MRD x PNT_{01})
- Malayan Red Dwarf x Panama Tall Monagre(MRD x PNT_{02})
- Malayan Yellow Dwarf x Mexican Pacific Tall 14 (MYD x $MXPT_{14}$)
- Malayan Yellow Dwarf x Mexican Pacific Tall 9 (MYD x $MXPT_{09}$)
- Malayan Yellow Dwarf x Mexican Pacific Tall 2 (MYD x $MXPT_{02}$)
- Malayan Yellow Dwarf x Panama Tall Aguadulce (MYD x PNT_{01})
- Malayan Yellow Dwarf x Panama Tall Monagre (MYD x PNT_{02})
- Malayan Yellow Dwarf x Mexican Pacific Tall 10 (MYD x $MXPT_{10}$)

These hybrids have progenitors that demonstrated resistance to Lethal Yellowing. The experiment was established in October 2002 in the coast of Tabasco, Mexico. The results revealed that hybrids flowered in 2.5-3.0 years after planting and have potential to benefit smallholders.

Establishing a framework and selecting project sites for the nation-wide deployment of coconut-based poverty reduction interventions in coconut growing communities using COGENT's 3-pronged strategy in Mexico

A socioeconomic study in five coconut growing communities in Mexico was carried out to identify suitable pilot communities and groups that could undertake poverty intervention projects. COGENT's 3-pronged strategy in helping poor coconut farmers, especially women, improve their incomes and living standard, will be tested under this project in one community. The project aims to::

1. Increase yields and incomes by deploying high-yielding; high-value multipurpose and adapted coconut varieties and hybrids using locally produced seednuts;
2. Increase incomes by promoting the production and marketing of high-value products from the meat, husk, shell, water, wood and leaves and identifying suitable varieties for these uses; and
3. Increase food security and incomes per unit area per unit time through intercropping and livestock/fodder production.

Use of biofertilizers for sustainable production

Technology has been developed on biofertilizer application for Atlantic Tall coconuts in Gulf of Mexico. The advantages of using biofertilizer are its low cost and ease of application. This biofertilizer is being promoted to help farmers increase yields and farm profitability.

Results/outputs and their significance

Zizumbo *et al.* (1998) conducted a 7-year evaluation of Tall-type coconuts from the Atlantic and the Pacific in Mexico. The Tall cultivars Guerrero 2, Jalisco 1, Michoacan 2, Colima 1, Colima 2 and Colima 3 exhibited some form of resistance to LYD. These genotypes were used as male parents to develop new Dwarf x Tall hybrids, some of which are being tested under the CFC-funded 'Multilocation trials to identify suitable coconut hybrids in Africa, Latin America and the Caribbean'. Other hybrids from these genotypes are being evaluated under two different experiments with the same purpose of finding resistance to LYD. Carrillo (1998) and Dominguez (1994), after nine years of evaluating the coconut hybrid 'Chactemal', found that it has high resistance to LYD in trials established in two Mexican towns. The hybrid is now being propagated in four seed gardens for dissemination and planting in LYD-devastated areas. However, as the current seednuts production can only cater to the planting needs of approximately 700 ha per annum, it cannot keep up with the rate of spread of the disease. Related to this, Dominguez *et al.* (2003) developed a technology to produce Dwarf x Tall hybrids with a productivity of 150 seednuts per palm per year. This technology, developed under the project entitled, 'Mixed Seed Garden Production of Coconut Hybrids' consists of using male and female parents in the same field, cauterizing the spikelets after the emasculation and applying Gibberellic acid at 100 ppm when concluding the pollination using bees. Currently, about 3 200 ha in Mexico have been planted with LYD-resistant hybrids and growing at a rate of 900 ha per year.

With regards to the rehabilitation of old Atlantic Tall stands, which were abandoned when world copra prices dropped, Castillo *et al.* (2003) found that with two applications per year of Micorriza + *Azospirillum* + 45-35-60 yield could be increased to 872 kg/ha, compared with the yield of the plantation before the application of the treatments that was of 542 kg/ha. This represents a yield increment of 61%. The application of *Azospirillum* with 816 kg/ha gave an increment of 50% yield. This technology is very economical and could allow coconut farmers to increase incomes as well as to conserve their precious genetic resources.

Suggested next steps

In Mexico, the following are the priority activities to develop the country's coconut genetic resources:

1. Identification, development and propagation of LYD-resistant Tall coconut varieties using open pollination; and
2. Establishment of a coconut genebank in Tabasco dedicated to the conservation and propagation of LYD-resistant hybrids/varieties.

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Latin America and the Caribbean

Status of coconut genetic resources research in Guyana

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Introduction

In Guyana, coconut (*Cocos nucifera* L.) ranks third, next to rice and sugar, among the most economically important crops. In spite of this, the potential of the crop has been largely underexploited and poorly developed. Coconuts contribute only approximately 1% to the total gross domestic product (GDP) of the country, an under achievement, considering its priority ranking in the agricultural sector.

It is estimated that there are 24 000 ha under coconut production, with an average annual production of 92 million nuts. In order to increase and sustain the current levels of production to meet market demand for greater economic efficiency, it is imperative that the issue of increasing coconut productivity be urgently addressed. According to Paul (1999), varietal improvement is the most expedient approach to resolving low productivity and consequent economic inefficiency. He further stated that varietal enhancement necessitates an analysis of the genetic structure (population level) and production potential of the diverse types, forms, strains and varieties grown in Guyana.

This article describes the coconut varieties and forms, and pests and diseases of economic importance in Guyana. A summary of the proposed coconut R&D development project for Guyana is also discussed.

Coconut varieties and forms

Coconut is grown widely on the coastal regions of Guyana, primarily along the Pomeroon River, in the Essequibo Coast, East Demerara, and West Berbice and on the Corentyne Coast. Coconut is mainly processed into cooking oil. Average copra yield from 100 nuts ranges from 13 to 16 kg. The use of tendernut as a nutritive beverage is very popular in Guyana.

Commercial holdings of coconut are mainly planted with two types of the Tall variety and two types of the Dwarf variety. The Tall types are the predominant source of copra, while the Dwarf variety is specially grown for their sweet water. One variant of intermediate height, known as 'Bastard Nut', is grown in the Pomeroon River area and is cultivated for both copra production and for its sweet water, although its copra yield is inferior to the Tall types.

Tall types

The most common Tall types existing in the country are the Jamaica Tall and the Panama Tall, each consisting of two basic colour forms: green and bronze. The Jamaica Tall bears long, angular nuts with distinct ridges and a thick mesocarp. Dehusked, its nuts are also angular and pointed at the end. On the other hand, the Panama Tall fruits are much more spherical with thinner mesocarp. These two types may be considered the 'original' Tall types in Guyana. Another variant of the Tall type found on the Coastal Corentyne (No. 60 Village), as reported by Manthriratoa (1980), is a type with spherical, medium-sized nuts but with a pronounced dark pink mesocarp. Several variations in epicarp colour forms have also been observed. Generally, commercial stands could not be classified on this criterion alone. Farmers, however, could distinguish between the two Tall types known as Clara Nut and Cocrit Nut. Clara Nut is similar in character to the Panama Tall. Cocrit Nut, on the other hand, seems to combine the nut characteristics of the Jamaican Tall and the Panama Tall.

The Cocrit Nut is regarded as a 'nut number' type rather than a 'nut size' type. Fruits of the Cocrit Nut are more spherical than oblong, with a thin mesocarp and thick kernel. Nut size ranges from small to large, with trees of larger nuts being less prolific. Commercial copra producers prefer the '5-year' (five years to begin production) nuts with an intermediate nut size, high yield and precocity.

The Clara Nut is a 'nut size' type. Husked nuts are large and spherical, with a high water capacity but thin kernel. The coconut water of this type is described as sweet and is favoured over all the other types grown for their coconut water. The hectarage devoted to Clara Nut, however, is minuscule compared to those variants preferred for copra.

A preponderance of Tall types can generally be found in all commercial holdings. However, in the Pomeroon River area, there is a higher frequency of Dwarf types in commercial holdings. In all commercial plantings, demand for new planting materials is generally for the Cocrit Nut type.

Dwarf types

Commercial Dwarf types are mainly of the green and yellow '3-year' (three years to begin production) variants. Manthriratoa (1980) described the Green Dwarf as being similar to the Brazilian Green Dwarf in growth habit, number of nut per bunch and size of nuts. The Yellow Dwarf, however, is different from the Malaysian Yellow Dwarf, in having a larger nut size and a less intense yellow colour in petioles and epicarps of the nuts. A third Dwarf type variant is the Red Dwarf (Orange Dwarf), restricted mainly to the Pomeroon River area. The Red Dwarf is similar to the Red Dwarf of India and Sri Lanka and the Malaysian Dwarf. Manthriratoa (1980) suggested that this variant may be a recent introduction from a Caribbean Country. Another variant, the Bronze Dwarf (so-called because of its bronze epicarp), is a relatively new find of about four years ago. The Bronze Dwarf was reportedly introduced from Surinam. Currently, there are only a few homesteads with this variety, but the current demand suggests it has the potential to spread rapidly to commercial holdings.

Bastard nut

Bastard Nut is predominately recognized in the Pomeroon River area. Manthriratoa (1980) attributed the origin of this variant to natural cross pollination between Dwarf and Tall types, being an apparent Dwarf x Tall hybrid. Bastard Nuts show marked hybrid vigour in trunk and leaf size, number of bunches produced per year and number of nuts per bunch.

Pests and diseases

The major pests of coconuts in Guyana are the coconut caterpillar (*Brassolis sophorae* L.); moth borer (*Castnia daedalus* Crammer); and Azteca ant-scale complex. Of the three predominant coconut pests identified in Guyana, the coconut caterpillar is considered the most destructive.

On the other hand, the major diseases of coconuts in Guyana are: cedros wilt, red ring disease; and bud rot. None of these diseases poses serious threats to the coconut industry in Guyana. It is also worthwhile to note that there is no reported case of Lethal Yellowing Disease (LYD) in Guyana.

Proposed coconut R & D projects for Guyana

Varietal improvement

Projects on varietal improvement shall address the immediate breeding objectives of increased yields, early maturity and disease resistance, especially against LYD. Breeding strategies shall include the following:

Standardization of evaluation techniques. Not much information is documented in Guyana on the evaluation procedures for coconut. In order to ensure that evaluation results be comparable with those obtained by evaluation programmes in other coconut-producing countries, it would be necessary to adopt the standard protocols for such evaluation programmes.

Characterization of locally-adapted germplasm resources. To date, monitoring of coconut germplasm resources in farmers' fields has established the location and prevalence of four Dwarf varieties. There are obvious variants of the Tall types, especially those of the intermediate or 'Bastard' types. However, unlike other crops cultivated in Guyana, it is not the habit of farmers to assign names to prominent variants of coconut. For this reason, assembling local coconut collections and characterizing them through conventional agronomic and morphometric methodologies could prove to be quite difficult.

Faced with a wide range of cultivated variants, it will be most appropriate to focus on analysis relating the observed pattern of traditional cultivation practices with the prevalence of coconut genetic diversity. This is where the application of DNA marker technology, like AFLP, becomes relevant. Elucidating the structure of molecular diversity, for example of 'Bastard Nuts', will assist in establishing their genetic origin and structure.

Hybrid coconut production. High-yielding varieties are the best way to mitigate low crop production efficiencies; low productivity being the most serious limitation to the viability of the coconut industry in the country. Despite the relatively wide range of germplasm resources available locally, it is apparent that the current rate of varietal improvement is still inadequate to sustain the development of the coconut industry. The solution is basically one of utilization. The performance of non-conventional and conventional Dwarf x Tall hybrids, produced locally, has been reported to be satisfactory. The potential genetic diversity of locally available Tall, Dwarf and 'Bastard Nut' germplasm opens up the possibility for testing a number of combinations. In addition, the introduction of refined germplasm and superior accessions of known performance suitable to Guyana's growing conditions and production circumstances will not only expand the genetic base of existing germplasm but also greatly magnify the spectrum of possible hybrid combinations. Networking with regional and international coconut R&D programmes is therefore necessary. In this regard, three options for hybrid research may be exploited:

- **Introduction and evaluation of elite hybrids** to identify hybrids suitable to nut production in Guyana. It is anticipated that many hybrids are presently available from the existing breeding programmes of other coconut growing countries that could be widely tested, probably in a regional setting. This is intended to have a continuous, medium-term impact;
- **Development of hybrids using proven progenitors,** the objec-

tive being to deliver potentially superior hybrids in the shortest time possible. This option will require the application of DNA markers; and

- **Hybrid coconut development using combinations of superior inbred Dwarf lines and Tall non-inbred progenitors.** Some of the progenitors will include the parental lines presented in the first option. The objectives, in addition to developing hybrids, are to determine the combining ability and heterotic pattern cum grouping of adapted progenitors using DNA analysis; and to obtain information on genetic diversity and structure of the local coconut germplasm. This then will set the stage to better managed and maintained high level on-farm coconut genetic resources diversity. Specifically, the project will determine the level of inter- and intra-varietal diversity, with the objective of establishing a breeding population which ultimately will have to be a comprehensive national coconut breeding programme. A further benefit of DNA typing of local coconut germplasm is that it will enable the determination of the requirements for infusing exotic germplasm material. However, until DNA typing techniques become accessible, *in situ* maintenance and monitoring will continue to be in the front line of the country's coconut genetic resources conservation strategy.

Development of disease indexing potential

In order to adopt a pre-emptive strategy to control LYD, the exchange of exotic germplasm and development of disease indexing capability need to be expedited. With minimum staff training and provision of the necessary equipment and materials, the Tissue Culture Laboratory, in conjunction with the Plant Protection Laboratories of the National Agriculture Research Institute (NARI), can accommodate a LYD screening facility. Of specific value is diagnosing the early occurrence of LYD so that its potential damage can be mitigated.

Coconut tissue culture

As a useful complement to the conventional nursery method, embryo culture technique has the potential of shortening the generation time to establish hybrids and their progenitors. Moreover, this technique, combined with disease indexing, will expedite the introduction of exotic germplasm and in the long term establish the capability for cloning superior palms through tissue culture. With adequate training, the tissue culture facility of NARI can also facilitate this procedure.

Collaborative coconut quality evaluation

The importance of copra quality should not be neglected. Quality adds value to copra. The experience of large-scale copra processors will be invaluable in this aspect of research. The processing companies may see it necessary to jointly finance this sector of coconut research in order that they also fully profit from generated technologies.

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Latin America and the Caribbean

Status of coconut genetic resources research in Jamaica

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Introduction

The coconut is not indigenous to Jamaica. The prevailing opinion is that it was first introduced to the Caribbean and Atlantic coasts of South America about the middle of the 16th century (Purseglove 1968). Initially, coconuts seemed to have been planted near harbours and coastal settlements but later, with the expansion of plantation agriculture, the crop was grown inland and by 1681, when Hans Sloane visited Jamaica, coconuts were widespread. By the end of the 19th century, the coconut had become a plantation crop and flourished in many parts of Jamaica especially on hillsides, which are not suitable for sugarcane, located mostly in the wetter eastern section of the island.

At the beginning of the 20th century, the majority of the coconuts grown commercially were of the Atlantic Tall (Jamaica Tall) variety but old records showed that there were at least four other varieties, including the King Coconut introduced from Sri Lanka in 1869. In 1973, Captain Bligh brought coconuts along with breadfruit to Jamaica from Tahiti.

Following periods of severe hurricane activity in 1903, 1904, 1912-1917, large numbers of nuts of the Panama Tall variety were imported from the San Blas Islands. Again, in 1922, there was further importation of nuts from Panama. In 1921, after the Panama Canal had been opened, a small number of seednuts of the Niu Leka Dwarf variety were brought to Jamaica from Fiji. The Niu Leka gave rise to two local populations: Tulloch Dwarf and Fiji Dwarf. These have not been of much commercial value. In 1933, 12 open-pollinated seednuts from two hybrids of Malayan Dwarf x Niu Leka were introduced. The third and fourth generation selections, locally known as Fiji-Malayans, are still being used in the country's breeding programme.

From 1938 to 1940, a few selected red-fruited Malayan Dwarf seednuts were introduced from the Caribbean island of Trinidad and from these a population of over 10 000 palms was established in the western part of the island. It was in that plantation that resistance to lethal yellowing was first documented. In 1939, about 150 seednuts from red- and yellow-fruited Malayan Dwarfs were introduced from Florida. Large-scale introductions of Malayan Dwarf seednuts (red, green and yellow colour forms) were made from the island of St. Lucia in 1945 and 1951 following severe hurricanes. A further introduction from the same source was made in 1968 as a consequence of the lethal yellowing resistance possessed by the Malayan Dwarf.

During the 1960s, in response to an outbreak of lethal yellowing disease in the main coconut growing region, germplasm from most of the countries in the Asia-Pacific region were introduced with international assistance for screening. These included Bougainville Tall, Chowghat Green Dwarf, Fijian Tall, Indian West Dwarf, King Coconut, Malayan Tall, Malayan Red Dwarf, Malayan Yellow Dwarf, Malayan Green Dwarf, Niu Leka Dwarf, Peru Tall, Rangiroa Red Dwarf, Rangiroa Tall, Rennell Tall, Rotuma Tall, Samoan Tall, Sarawak Tall, Seychelles Tall, Solomon Islands Tall, Spicata Tall, Spicata Red Dwarf, Tahitian Tall, Thailand Tall, Tonga Tall, Vanuatu Tall and Yap Island Tall. In addition, pollens of Cambodia Tall, Tahiti Tall, Mozambique Tall and Cameroon Red Dwarf were obtained from Institut de Recherches pour les Huiles et Oléagineux (IRHO).

As a part of the multilocation trial funded by the Common Fund for Commodities (CFC), six F_1 hybrids were introduced into Jamaica in 2000 and 2002. In 2001, seednuts from selected Panama Talls in Mexico and of two locally produced F_1 hybrids were imported into Jamaica.

Germplasm and hurricanes

Jamaica is located in the hurricane belt and during the period 1886-1986, the island experienced 171 'events' (hurricanes) of varying intensities (Gray 1990). Over the years, multipurpose variety trials have yielded useful data on windstorm damage. Following a hurricane in 1944, it was reported that 60% of 30 560 Jamaica Talls were destroyed compared with only 6% of 5120 Panama Talls (Coconut Industry Board 1962). After another hurricane in 1980, it was observed that the Malayan Dwarf was not as resistant to storm damage as the Panama Tall and the F_1 hybrids of Malayan Dwarf x Panama Tall and Malayan Dwarf x Jamaica Tall. Yaps Talls, Seychelles Talls and late generation Fiji-Malayans showed high windstorm resistance (Coconut Industry Board 1980). Data collected from variety trials in six sites following a severe hurricane in 1989 showed that of the eleven varieties involved, the Malayan Dwarf was the most susceptible and Malayan Dwarf x Panama Tall (Maypan), the least damaged. Data gathered from wind-thrown palms that were recovered suggested that canopy may be of less importance in determining wind damage than trunk height and diameter of the bole (Johnson *et al*. 1994).

Germplasm and lethal yellowing

When lethal yellowing appeared in the main coconut belt in 1961, all varieties being grown locally were tested for disease resistance. Fortunately, the Malayan Dwarf, a variety introduced earlier, was found to have good resistance. In addition, it was precocious and highly productive under good conditions. Farmers were encouraged to replant the variety in affected areas and in underplant areas not yet affected by the disease. Unfortunately, the Malayan Dwarf had relatively low oil content and did not do well under marginal conditions hence, the search continued for other resistant varieties. With the assistance of the Overseas Development Administration (ODA) and Food and Agriculture Organization of the United Nations (FAO), germplasm was collected in Southeast Asia and the Pacific. These were screened for resistance in field trials. When it became obvious that none of the introductions was more resistant than the Malayan Dwarf, a hybridization programme was started in an attempt to combine in the F_1 progeny the high disease resistance of the Malayan Dwarf with the large fruit size and hardiness of the Talls. One of the early crosses, Malayan Dwarf x Panama Tall, called Maypan, was found to be productive and resistant. A system was then devised to produce it commercially.

Screening of introductions for lethal yellowing resistance has been ongoing and other F_1 hybrids have been produced and tested (Been 1981), but to date the Maypan remains the most popular variety accounting for more than a half of the palms grown commercially.

During the mid 1990s it was observed that, in certain places, Malayan Dwarf and Maypan palms were exhibiting lethal yellowing mortalities at a rate higher than previously observed. The trend continued and now the disease is destroying thousands of palms in the main coconut growing areas. Work done on the pathogen suggests that the phytoplasma may have mutated and/or exceptional environmental conditions may be combining to produce situations, which are extremely favourable for the development and spread of the disease.

Screening and breeding for lethal yellowing resistance will continue with every effort being made to import new germplasm for further evaluation on lethal yellowing resistance.

IPGRI/COGENT activities in Jamaica

Since the 1990s, the International Plant Genetic Resources Institute's International Coconut Genetic Resources Network (IPGRI/COGENT) has been supporting activities related to germplasm conservation and use in Jamaica, especially in the areas of capacity building and research undertakings.

In 1997, Jamaica received expert technical assistance in formulating a coconut regional project proposal for Latin America and the Caribbean. In the area of training and human resource development, a regional STANTECH (Standardized research technique in coconut breeding) training course was held in Jamaica in 1997 and the Botanist/Plant Breeder of the Coconut Industry Board attended a similar regional course in Africa. Two COGENT-sponsored meetings were hosted by Jamaica in 1997 and 2002.

Currently, Jamaica is participating in the Common Fund for Commodities (CFC)-funded Multilocation Trials to identify suitable coconut hybrids/varieties for Africa, Latin America and the Caribbean. The Department for International Development (DFID)-funded project entitled 'Establishing a Framework and Selecting Project Sites for a Nationwide Deployment of Coconut-based Poverty Reduction Interventions in Coconut Growing Communities using COGENT's 3-pronged strategy in Jamaica' has also been completed.

The Coconut Industry Board has been the implementing agency for both projects. The Board, a statutory body established in 1945, is responsible for and advises the government on matters regarding the Jamaican coconut industry. Prior to the establishment of a research department in the Board, the Ministry of Agriculture was responsible for coconut research and development.

Conclusion

The use of introduced germplasm has enabled the local coconut industry to survive despite hurricanes and lethal yellowing disease, the two main threats to the industry.

The resurgence of lethal yellowing necessitates a renewed search for and use of germplasm with good resistance to this disease. The eventual solution to the problem may lie in the realm of genetic engineering, but until then, conventional breeding procedures would have to be used.

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South Pacific

Status of coconut genetic resources research in the Cook Islands

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Introduction

The Cook Islands consist of a group of 15 small islands scattered between 167° west and 8-23° south of the equator. Its total land area is 237 sq km, and the country has one of the largest Exclusive Economic Zones in the Pacific Region covering approximately 1.8 million sq km of ocean. The islands are geographically divided into two groups: the Northern Islands and the Southern Islands. The two island groups have marked differences in their agricultural activities. The Northern Islands group remains relatively isolated from the Southern Islands, with the latter continuing to indulge in more diversified agricultural practices. The Southern Islands group has a cooler climate and more fertile soil enabling a wider variety of agricultural production as compared with the Northern Islands where the soil is relatively unfertile and has poor water holding capacity, thereby limiting agriculture-related activities.

A census of agriculture in 2000 reports a total cultivated area of 1945 ha or 8.2% of the total land area, a drop of 3.3% from data collected in the previous census in 1988. Coconut occupied 34.5 ha of the cultivated land, which includes intercrops in a coconut-based farming system. The proportion of land under coconuts is somewhat higher on the atolls. Coconut is widely used, especially in the rural communities and the Northern Islands, for food and other numerous purposes. Copra, in previous years, constituted a major export commodity. However, as international demand for the commodity dropped, copra production became a non-viable venture.

In April 2000, Dr Roland Bourdeix, coconut palm geneticist and breeder from the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) visited the Cook Islands, with the support of COGENT, from 30 March to 13 April 2000 to collect data on coconut genetic resources in Cook Islands. Tiara Mataora, Senior Research Officer with the Ministry of Agriculture acted as the local project leader. The coconut germplasm collecting, characterization and conservation were conducted on the islands of Rarotonga and Aitutaki. The project aimed to survey and collect available data on diversity of local coconut populations which will be used for breeding and to mitigate genetic erosion due to population pressure, palm ageing and natural hazards.

Collecting and characterization of coconut germplasm

The project's specific objectives are as follows:

1. Train coconut researchers on germplasm collecting, and on coconut breeding research techniques using the International Coconut Genetic Resources Network's (COGENT) standardized research techniques in coconut breeding (STANTECH) Manual;
2. Collect germplasm initially from one or two sites then to another three to seven sites;
3. Characterize germplasm collected from the sites to identify populations and conserve desirable germplasm;
4. Plant and manage collected germplasm in a genebank;
5. Characterize the collected germplasm and submit passport and characterization data to COGENT's International Coconut Genetic Resources Database (CGRD); and
6. Send embryos of selected populations to the Secretariat of the Pacific Community (SPC), which will culture the embryos and subsequently transfer the resulting *in vitro* seedlings to the International Coconut Genebank for the South Pacific (ICG-SP) in Papua New Guinea.

Problems and opportunities addressed by the project

The Cook Islands lacks the necessary human resources, particularly a coconut expert or a full-time coconut research staff, to carry out coconut genetic resources research, limiting the exploitation of the potential of coconuts and its products.

It is anticipated that further survey activities shall include populations in the other islands of the country, such as the island of Pukapuka. The inclusion of other islands should provide a better understanding of coconut genetic diversity in the Cook Islands.

Training activities sponsored by COGENT

A regional training course was organized on standardized research techniques in coconut breeding techniques which was held at the Agricultural Research and Training Centre in Vanuatu from 29 June to 9 July 1999. The training course was part of the Asian Development Bank-funded COGENT project entitled, 'Coconut Genetic Resources Network and Human Resources Strengthening in Asia and the Pacific Region'. A researcher from the Cook Islands participated in this activity.

Results/ outputs of the germplasm survey

The islands of Rarotonga and Aitutaki were surveyed. A visit to the island of Pukapuka was initially planned; however, this was impossible as there was no air link with the islands at the time of Dr Bourdeix' visit. Pukapuka is an atoll island and was chosen for its isolation from most other islands and, therefore, may hold some unique coconut ecotypes. Aitutaki, on the other hand, is both a volcanic and atoll island (usually referred to as 'almost an atoll').

Seednuts from seven populations were collected, taking into account the results of the previous generalized sampling strategy and results of the participatory survey in Aitutaki Island. Due to time constraints, it was not possible to make all the required characterizations for the seven populations.

Description of surveyed populations

Cook Islands Tall Seven-in-One (COKT01)

In the centre of Avarua, capital of the Island of Rarotonga is a group of seven Tall palm trees growing in a circular and, what appears to be, a singular clump. Old folks in the area believe that the 'clump' actually originated from just one palm. However, several historians tell otherwise. To settle the issue once and for all, seednuts and leaflets from the trees were collected for DNA analysis to determine whether these palms are real 'septuplets', full-siblings, half-siblings or are entirely unrelated. Some 105 seednuts were collected, but many either were pre-germinated on the tree or are too young to harvest. Sixty albumen cylinders were obtained that finally gave 52 excised embryos, which were cultivated *in vitro* at SPC's tissue culture laboratory in Fiji. The resulting *in vitro* seedlings were later transplanted to the ICG-SP which is hosted by PNG.

The summary descriptions of the surveyed coconut population in Cook Islands and related ongoing DNA analysis of the germplasm are presented in Table 1.

Significance of the survey and impact on Cook Islands' coconut genetic resources

The results of the germplasm survey should assist with the assessment of coconut diversity in Cook Islands. It is anticipated that further exploration and collecting activities will include populations in other islands of the Cook Islands group.

The collections made during this study will conserve precious germplasm which could be used to develop better varieties for the atolls and enrich the collection of the ICG-SP. The description and the molecular

Table 1. Description of the surveyed coconut populations in Cook Islands

Tree No.	Proposed Name and Abbreviation	Origin	Remarks
1	Cook Islands Tall – Sweet Husk (COKT03)	Rarotonga	Husk from the nut can be removed by hand. The internal part of the husk is sweet.
2 to 13	Cook Islands Tall – Papaaroa (COKT03)	Rarotonga	One mature fruit and several leaflets were harvested from each palm for molecular analysis. Palm No.2 had big, elongated brown nuts with a relatively high proportion of husk.
14	Red Dwarf	Rarotonga	There were no seednuts harvested for embryo extraction as similar cultivars are available in Papua New Guinea. Leaflets were collected for DNA analysis.
15 to 29	Cook Islands Dwarf – Totokoitu (COKD01)	Rarotonga	Ten palms were sampled for fruits and DNA analysis.
30 to 50	Cook Islands Tall – Vivi (COKT04)	Aitutaki	Seven or eight palms were sampled for DNA analysis.
51 to 80	Cook Islands Tall – Golf (COKT05)	Aitutaki	Ten palms were sampled for leaf analysis.
81	Cook Islands Dwarf – Vaikoa COKD02)	Aitutaki	One palm was sampled for DNA analysis.
82 to 88	Cook Islands Tall – Seven-in-One (COKT01)	Rarotonga	Seven palms were sampled for DNA analysis.
89 to 91	Cook Islands Tall – Papua River (COKT06)	Rarotonga	The palms are remnants of an old inland plantation. Sampling was done only for molecular analysis.

markers analysis of these populations will not only generate information on genetic diversity within these collections but also improve the knowledge on the origin and the dissemination of coconut in the Pacific Islands, and help facilitate the exchange of important cultivars with other countries.

Suggested next steps

The selected or identified populations of Tall and Dwarf coconuts with good characteristics will be continuously observed and may be used for further genetic breeding programmes. Selected populations of coconut materials transferred via tissue culture to PNG where the conserved genetic pool is located would continue to provide such materials for future research, not only to Cook Islands but also to other South Pacific countries.

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South Pacific

Status of coconut genetic resources research in Fiji

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Introduction

Coconut germplasm collecting, conservation and varietal description has been an ongoing collaboration between the Ministry of Agriculture, Sugar and Land Resettlement (MASLR) and the International Plant Genetic Resources Network (COGENT) since1994. Fiji has an established germplasm collection consisting of initial eight accessions at the Taveuni Coconut Center. These accessions have not been fully characterized. To better utilize germplasm held in such collection characterization is vital. Characterization carried out in this activity is limited to morphological description using COGENT's standardized techniques in coconut breeding (STANTECH) manual. The data collected from the evaluation were sent to the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) for inclusion in the International Coconut Genetic Resources (CGRD) database.

COGENT consultants assisted our national projects by assessing our R&D capacity and also in helping MASLR to identify projects and training necessary and adapted to our situation.

COGENT initially provided training for developing the National Coconut Research staff on using STANTECH. The knowledge and skills acquired through this training was useful and complementary to their existing skills. Also COGENT's support in the evaluation of Fiji germplasm collection enabled us to know better the performance of the different accessions, which would assist us in recommending to farmers and policy makers the best varieties to be used for planting.

Researchable problems and opportunities addressed by research conducted in the country

Hybrid evaluation trial

The evaluation of Dwarf x Tall hybrids is one of the major activities carried out. Four Dwarf by Tall hybrids consisting of Malayan Red Dwarf as their female parents and Fiji Tall, Niu Leka, Rennell Island Tall and Rotuman Tall as their male parents were used. These hybrids were compared against Fiji Tall in a randomized complete block experiment. Like the establishment and evaluation of the coconut germplasm, this activity was established with the assistance of the European Community and CIRAD. Through COGENT, we were able to continue the evaluation. On a bi-monthly basis, yield in terms of the number of nuts per palm were collected and a fruit component analysis was carried out. The results of this trial were used in planning Fiji's breeding and replanting programmes.

New collections established

Several collections were made for varieties, which existed as non–commercial varieties, but they had value-adding potentials. These potentials were never exploited previously. Hence, under the Asian Development Bank (ADB)-funded project, these varieties were collected and conserved at Taveuni Coconut Center for future research activities. On the other hand, several populations of Fiji Tall were studied for genetic diversity. The results showed that there was not much difference between the populations.

Diversification of coconut uses

In the farmer participatory research conducted by the Research Division, Ministry of Agriculture, Fisheries and Forests, the constraints facing coconut production in Fiji include lack of knowledge of farmer's varieties and uses especially by the younger generation. In this survey, 21 varieties were identified and several uses. This reveal the potentials existing in communities for value adding which are not being tapped.

Projects coordinated by COGENT in Fiji

Evaluation of coconut germplasm collection and hybrids in Fiji

Selection and breeding of high-yielding varieties (ADB/ COGENT PHASE 1)

The Taveuni Coconut Center was established in 1987 to look into Fiji's ailing coconut industry. To set up this station, the government purchased 384 ha of land for the construction of infrastructure and establishment of seedgardens and trials. The programme was initiated to address the declining production of coconuts through production of high yielding hybrids seednuts and seedlings for rehabilitation. During this time, COGENT coordinated an ADB-funded project to accomplish the following objectives: 1) evaluate and characterize the existing germplasm collection at Taveuni Coconut Center; 2) maintain and monitor performance of four hybrids compared to Fiji Tall; and 3) monitor nine on-farm demonstration plots.

The evaluation of the hybrids and also the germplasm collection include data on yields in terms of copra per nut and per palm and also cyclone resistance of the different accessions. The results are presented in Table 1.

Collecting of coconut genetic resources in Fiji (ADB/COGENT Phase II)
The phase II project focused on the study of various populations of Fiji Talls in all provinces of Fiji and collecting other cultivars which were not previously considered and conserved, and were under threat of genetic erosion. Twenty-four populations of Fiji Talls were studied in eight islands and these include the three main islands namely Viti Levu, Vanua Levu and Taveuni and other islands in the eastern division. The objective of the study was to confirm the diversity that exists between the populations of Fiji Tall so that appropriate conservation strategies can be designed and implemented. The results revealed that there is not much difference among populations. On the other hand, the new collections made included Niu ni Magimagi, Niu Buludrau, Uto Gau, Niu Kitu and Stripped variety. The passport data have been included in the CGRD. See Tables 2 and 3 for summary of collecting activities.

Sustainable use of coconut genetic resources to enhance incomes and nutrition of coconut smallholders in the Asia and Pacific region

Component 1: Farmer participatory surveys
Farmer participatory surveys using participatory rapid appraisal (PRA) tools were conducted in five villages selected from four islands in the archipelago. The objective was to identify farmer's varieties and multipurpose uses of coconuts. The focus of the study went beyond the above two themes (i.e., the general preoccupation of the community in relation to coconut plus the impacts of coconuts in their respective community). The five villages identified several cultivars and uses (Table 4).

Component 2: Evaluation and conservation of tendernut varieties
Three major activities were carried out:

1. Initial market survey - local and overseas (Australia);
2. Transferred seednuts of tendernut variety to the western division for raising and distribution to farmers; and
3. Characterized tendernut varieties.

Table 1. Results of germplasm evaluation

Cultivar	Average dried Copra / nut (g)	Average number of nuts produced per palm per annum	Average yield copra / ha (tonnes) 10 x 10 m (triangular spacing) = 115 palms /ha
Dwarf			
Niu Leka	236	25	0.7
Malayan Green	152	43	0.8
Malayan Red	166	36	0.7
Malayan Yellow	179	41	0.8
Hybrids			
MRD x FJT	213	29	0.7
MRD x NLAD	262	27	0.8
MRD x RIT	279	31	1.0
MRD x RTMT	269	33	1.0
Tall			
Fiji Tall - Taveuni	240	24	0.7
Fiji Tall - Lakeba	248	29	0.8
Rotuman Tall	261	19	0.6
Renell Island Tall	355	15	0.6

Table 2. Fiji Tall population study sites

Date	Locality	Province	No. of samples characterized
Nov-97	Cicia Island	Lau	2
Jul-98	Taveuni Island	Cakaudrove	2
Jul-98	Nawaca	Bua	1
Aug-98	Lakeba Island	Lau	1
Sep-98	Rotuma Island	Rotuma	2
Sep-98	Navutulevu	Serua	1
Sep-98	Navua	Serua	1
Sep-98	Toga	Rewa	1
Oct-98	Savusavu	Cakaudrove	2
Apr-99	Saqani	Cakaudrove	1
Apr-99	Levuka	Lomaiviti	2
May-99	Natavea	Naitasiri	1
May-99	Navunibitu	Ra	1
May-99	Nailega	Tailevu	2
Jul-99	Vanua Balavu	Lau	2
Nov-99	Kadavu	Kadavu	2

Table 3. Data of the new collections carried out nationally

Date of collection	Collected from	Variety	No. of palms
November 1997	Cicia	Niu ni Magimagi	30
November 1997	Cicia	Niu Buludrau	35
September 1998	Rotuma	Uto Gau	12
September 1998	Rotuma	Stripped Nuts	15
July 1999	Vanua Balavu	Niu ni Magimagi	7
July 1999	Vanua Balavu	Niu Buludrau	21
August 1999	Cicia	Niu ni Magimagi	142
August 1999	Cicia	Niu Buludrau	20

Table 4. Coconut cultivars identified by the communities

	Komo	Bouma	Kanacea	Namuka- I- Lau	Nawaca
Elders	10	9	7	11	12
Women	11	8			12
Married Men	11	6		11	9
Youth	11	6		9	6

The market study revealed the following:

1. Fiji Tall variety is the major source of green coconuts (90 – 95%) and one of the problems encountered by farmers is difficulty of harvesting due to the height of the palms;
2. Lack of diversity in the green coconut belt areas (Rakiraki and Serua);
3. The stakeholders are unaware of the varieties of coconut locally available; and
4. A demand that cannot be satisfied is bigger size drinking nuts for overseas markets.

A nursery was established in the western division (Legalega Research Station) to raise the first batch of seed nuts from Taveuni Coconut Center. The seednuts were raised and established at the station as source of planting materials for tendernuts. Four Dwarf varieties were characterized for potential tendernut production and data sent to CIRAD for inclusion in CGRD in 1998.

Developing sustainable coconut based income-generating technologies in poor rural communities in Fiji

To increase incomes of coconut farmers, MASLR participated in COGENT's diversity-linked 'Poverty reduction in coconut growing communities' project, involving eight Asia Pacific countries. The project deployed and tested four income generating technologies: 1) production and marketing of high-value products from all parts of the coconut; 2) intercropping cash and food security crop; 3) livestock raising and feed/fodder production; and 4) establishment of community-managed seedling nurseries. The project was implemented in three coconut growing communities, namely Belego, Tukavesi and Cicia. The project involved 17 participants in production of high-value coconut products, 454 in intercropping and 32 in animal and feed/fodder production.

The project increased the incomes of participants by 2-5 times, enhanced their food security and nutrition, and more than 1000 coconut seedlings have been conserved on farm.

Training and capacity building

Two coconut research staff (Tevita N Kete and Vijendra Kumar) were trained in Vanuatu in 1996 on STANTECH and the former attended this training course through funding from French Embassy in Fiji. Apart from the above, Fiji benefited from the visit of COGENT consultants (M Hazelman and G Santos) who assessed the National R&D capability, assisted the national program in identifying common problems, opportunities and projects for network collaboration. COGENT also supported the scholarship of Tevita Kete who obtained his Master's degree from the University of the Philippines at Los Baños.

Interpretation of significance or impact of output

1. The results obtained from the evaluation of the collections will be useful for the coconut industry for rehabilitation programmes, especially the effect of the cyclone on varities. Current recommendation for the rehabilitation programme is to use Fiji Tall, Rotuman Tall and Niu Leka apart from hybrids of Rotuman Tall crossed with Malayan Red Dwarf.
2. Coconut research staff trained to execute and implement coconut research programs for the betterment of Fiji's coconut industry.
3. Collecting of coconut cultivars were done and collected accessions conserved for future use.

Suggested next steps

New collections

The new collections will be evaluated and characterized and multiplied for future breeding work. Most of the new collections made are varieties suitable for value adding, the potentials of which will be exploited.

Coconut rehabilitation

The results of the germplasm evaluation work will be used for selecting materials for replanting, as the cyclone of 2003 served as a test in determining the cyclone tolerance of the varieties existing in our collection.

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South Pacific

Status of coconut genetic resources research in Kiribati

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Introduction

Coconut dominates agricultural production in Kiribati as the crop provides one of the main components of the people's daily diet as well as drinks, copra for export, timber for construction, leaves for thatching, string and materials for handicrafts (Trewen 1985; Edward 1989; Beenna 2001). Edward (1989) commented that the total number of indigenous coconut plant species in Kiribati is very low, which is a reflection of the isolated location of the islands coupled with the infertility of the soil. Barr (1992) stated that 80% of the land area of the main Gilbert Group, where 93% of the population lives, is covered with coconut. The Agricultural Division has, for the last 30 years, conducted extensive research on coconut with assistance from the British Government. The emphasis on coconut improvement has been in response to the perceived importance of the coconut and its products in the lives of the people of Kiribati. The objective of most of the researches conducted has been confined to increasing coconut yields. Hence, two large-scale coconut plantation improvement schemes were devised; one aimed at improving traditional palm groves and the other targeted at rehabilitation and replanting.

These coconut plantation improvement schemes mainly involved improving the quality of existing stands of traditional palm groves with reasonable density (Barr 1992). Thinning of over-dense areas was done by poisoning senile palms and non-productive 'self-seeded' younger palms. The scheme was terminated in the early 1970s as it was exhausting resources. In addition, data recording was very poor and could not be used to justify the continuation of the activities.

Past coconut replanting schemes focused on replanting areas with less than 49 palms per hectare. The result of the scheme was quite disappointing as the actual production per hectare was far below expectations (Barr 1992). The problem was aggravated by poor or unsuitable planting sites, most of which were hard-pan or waterlogged.

Research activities conducted and results/ outputs

Experimental studies

Coconut management trials were carried out at different locations to address the problems encountered in implementing the two plantation improvement schemes previously mentioned. It was anticipated that the resulting recommendations would then be demonstrated and transferred to smallholder farmers to help them rehabilitate their old palms, including replanted farms in order to increase yields (Trewen 1986; Barr 1992).

Spacing/density. Three triangle pattern spacing were tested and conducted on a number of selected sites with variable rainfall, i.e. high and very low rainfall. The trials aimed to determine the optimum spacing for coconut growing. The results of the trials concluded that a spacing pattern of 9 m and 8 m was ideal especially for areas with high rainfall and good soil fertility.

Basic NPK requirements. Two trials were carried out to determine the optimal NPK combinations for coconut growing in the atolls under marginal and normal soil conditions. The treatments were combinations of annual applications of 0, 1, 2, or 3 kg/palm of potassium chloride (KCl) fertilizer; 0 or 1 kg/palm of triple superphosphate fertilizer; and 0, 1, 2, 3 kg/palm of IBDU (N) fertilizer. All palms tested also received a trunk injection of iron sulphate at the start of the trial. The results suggested that potassium was the most important nutrient for marginal soil areas and K deficiency could be corrected within three years by applying 1 kg KCl/palm/year. It was also found that nitrogen application increased coconut yields.

Manganese, copper and zinc trials. The trial examined the requirement for Mn (0 or 20 g/palm), Zn (0 or 8 g/palm), and Cu (0 or 3 g/palm) when applied with Fe and their interactions with applications of NPK. All the palms tested received a basal dressing of iron sulphate by trunk injection at the start of the trial. The results showed that there should be an optimum balance of Fe, Mn, Zn and Cu in order to promote good plant growth and production. It was also found out that Cu interacts with N to increase yields, while proper Cu and Mn combination improves N assimilation.

Trace elements and application trial for coconut seedlings. The trial investigated the optimum method for giving seedlings a long-term supply of Fe at the time of planting and also examined whether other trace

elements are required other than Fe. The trace element compounds used consisted of iron sulphate (75%), manganese sulphate (15%), zinc sulphate (7%) and copper sulphate (3%).
The compounds were applied using two doses of $FeSO_4$ (50 g and 375 g), following two different methods of application (applied to the husk of a seedling or buried near the seedling). For good growth, it was recommended that 50 g of $FeSO_4$ be applied to the husk while 200 g is recommended if the soil-covered method was followed.

Iron application trial. The trial compared the effect of four different iron compounds: iron sulphate, chelated iron, fritted iron (iron in glass) and iron fillings. The results showed that chelated iron was the fastest acting compound followed by iron sulphate, iron fillings and fritted iron. Application of iron compounds corrected iron deficiency and improved coconut growth.

Coconut demonstration project
The main objective of the project was to educate and assist farmers who wish to improve their coconuts. Activities included establishing demonstration plots on each island, organizing field days for farmers, conducting radio programmes about coconut improvement, and providing training on recommend crop management techniques.

Collaborative activities with the International Coconut Genetic Resources Network (COGENT)

Establishment of genebanks

A genebank has been set up in the Central Nursery. The hybrids were collected from different locations (islands) in Kiribati, including South Tarawa. Since studies have shown that Tall varieties in the country are not in danger of genetic erosion, the collecting focused more on Dwarf cultivars found in the country. How Dwarf varieties were introduced into the country remains a mystery. Some people surmise that these varieties were brought in illegally from neighbouring countries, as perceived from the local names given to these varieties. Dwarf varieties are sought after because they flower early (most within three years), they are suitable for making toddy and are high-yielding which can supply tendernut for drinking and are easy to manage. Given these qualities, selected Dwarf varieties are being used in breeding programmes to produce Dwarf x Tall hybrids. It is envisioned that the genebank would continue to supply planting materials to the public and serve as a conservation area for the collected varieties.

Capacity building

A coconut expert visited the country to assist in training the national coconut programme coordinator and to characterize existing coconut germplasm collections and set up a coconut germplasm conservation site in the country. Two local research officers have also been sponsored by COGENT to undergo staff development training on the use of the STANTECH (Standardized research techniques in coconut breeding) Manual in 1996 and 1999.

Significance of research outputs

The result of the replanting and rehabilitation schemes resulted to an increase in the land area for coconut. Various coconut researchers in Kiribati reported that more than 80% of the land was occupied by coconut alone (Trewen 1986; Edwards 1989; Barr 1992). The establishment of a genebank for Dwarf varietal accessions is a very significant step for coconut breeding, germplasm conservation and copra production improvement programmes, which would lead to the enrichment of the resource for the improvement of the culture and lives of I-Kiribati.

Suggested next steps

The introduction of new Dwarf varieties *in vitro* that could survive atoll condition should be one of the priorities in developing the coconut industry in Kiribati. Technical assistance from institutions such as Secretariat of the Pacific Community (SPC), International Plant Genetic Resources Institute/International Coconut Genetic Resources Network (IPGRI/COGENT), and the Food and Agriculture Organization of the United Nations (FAO) should be requested. Traditional methods of planting coconuts should be further investigated and adapted to modern technologies to improve and increase the production of coconut and the products derived from it.

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South Pacific

Status of coconut genetic resources research in Papua New Guinea

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Introduction

The PNG Cocoa and Coconut Research Institute (PNG-CCRI), established in 1986, is the research arm of the cocoa and coconut industries in the country. Priority research is currently focused on breeding, entomology, downstream processing, agronomy and farming system.

In the 1970s, a number of exotic coconut populations were brought into PNG, initially as planting material. These include Malayan Red and Yellow Dwarf (MRD and MYD), Renell Island Tall (RIT), West African Tall (WAT) and the Solomon Islands Tall populations. The MRD and RIT populations were used to produce the MAREN hybrid which is known to yield higher copra than either of its parents in the Solomon Islands where it was initially developed (Foale 1987). The MAWA (PB121) hybrid was also introduced for planting because of high yield performance as observed in the Ivory Coast. Unfortunately, these two hybrids did not perform well in PNG. The MAWA hybrid was not accepted by the growers as it produced small nuts compared to the local populations. They believe that large but fewer nuts involve less labour while still giving similar copra yield as that from palm with smaller but more numerous nuts. The local people have always preferred bigger fruits for drinking and they also seem to prefer the solid endosperm of the local types, which were considered sweeter and tastier than the MAWA hybrid.

When the MAREN hybrid was introduced to growers during the 1970s, it was found to be susceptible to three insect pests, namely: *Scapanes australis* (beetle), *Oryctes rhinoceros* (rhinoceros beetle) and *Rhynchophorus bilineatus* (black palm weevil). These three species are endemic only to the island provinces of PNG where the bulk of the copra is produced. The hybrid trial in the Gazelle Peninsula was devastated by these insect pests. The growers then reverted to picking seednuts from the best palms among the local open-pollinated Tall palms. Breeding work in the 1970s developed Dwarf x Tall hybrids with local Tall, with Karkar Tall (KKT) and Markham Valley Tall (MVT) as the pollen donors. These hybrids were then planted out in progeny trials throughout the country using the MAREN hybrid and RIT as controls. However, the results of the progeny testing were inconclusive because the trials were terminated prematurely due to lack of funds.

Germplasm collecting, conservation and utilization

In 1986, when PNG-CCRI was officially established, the institute took over the research on cocoa and coconut from the Department of Agriculture and Livestock (DAL). The main aim of the coconut breeding programme is to develop better and improved varieties for distribution to farmers. The coconut breeding related activities at that time were focused on germplasm survey, identification of the best populations, germplasm collecting and utilization in a national breeding programme (Faure and Moxon 1998).

From 1987 to 1992, the Australian Centre for International Agricultural Research (ACIAR) funded and supported a national 'Coconut Improvement Project' main focus of which was on germplasm survey, characterization and collecting (Ovasuru *et al.* 1993). By 1993, seednuts and pollen of over 50 different Tall and Dwarf populations from surveyed sites, PNG-CCRI's collection in Rabaul and from DAL research stations have been collected based on fruit component analysis (FCA) data. The seednuts from these collections were raised and planted at the Stewart Research Station (SRS) in Madang. Pollen from various Tall populations was used in crosses with MRD, MYD and PNG Brown Dwarf (PBD). The progenies are currently under test, predominantly for general combining ability (GCA) for yield (kg copra/ha), with the aim of selecting the best hybrids for distribution to farmers and growers. In addition, the programme emphasizes further prospecting, collecting of new germplasm and production and testing of Dwarf x Tall and Tall x Tall hybrids.

Development of the regional coconut genetic resources centre: The International Coconut Genebank for the South Pacific (ICG-SP)

In November 1998, the International Plant Genetic Resources Institute (IPGRI) and the Government of PNG, through the Department of Agriculture and Livestock, signed a Memorandum of Agreement formalizing the establishment of the International Coconut Genebank for the South Pacific (ICG-SP) with PNG-CCRI as host. The Food and Agriculture Organization (FAO) of the United Nations also signed the agreement in its capacity as trustee as witness. The ICG-SP is located at the SRS, located south of the equator at 5° latitude and 146° longitude.

The major roles of the genebank include the collecting, conservation, evaluation and utilization of selected and desirable coconut germplasm in the South Pacific region. In addition, the ICG-SP will eventually become a service centre to facilitate germplasm exchange and utilization amongst the COGENT network countries, especially among the Pacific Island Countries.

Other potential sources of germplasm

Research stations of the Department of Agriculture and Livestock

The research stations owned by DAL could hold introduced germplasm which may have not been sampled by the current breeding programme. These need to be visited and their germplasm collected for conservation in the ICG-SP. If these accessions found on the research stations have been listed in the designated list for introduction, they would be collected immediately and hence, save costs in importation.

Farmers' varieties

The use of farmers' varieties in the national breeding programme has great potential but is not fully explored, except under an ACIAR-funded project on germplasm survey which was conducted from 1987 to 1992. Potential local varieties will be surveyed and either pooled or catalogued collections conserved on farm for future requirements. However, such system of conservation is unpredictable as the farmer could replace the accession with other varieties. One way to safeguard this would be to enable the farmers to conserve the accession by providing some sort of incentives like production of high-value products from the conserved genetic materials.

The scattered coconut palms on the fringes of the mainland and outlying atolls of the country are in danger of being swept away by rising sea levels. These germplasm would be a priority for possible characterization, collecting and conservation. The inhabitants of some atolls depend on coconut for their entire livelihood, e.g., Motlok atolls in North Solomon Province, and they have special varieties cultivated for food and artefacts. The sweet husk variety is one of the varieties.

Some innovative farmers or large landholders have or may have done their own selections of good performing varieties that need to be sampled for direct use (pollen) or for conservation and further evaluation and utilization. Such populations need to be considered in the national breeding programme.

Synthetic varieties

The development of synthetic varieties is being explored to utilize the promising Tall populations to generate Tall composite hybrids. Experience and models for synthetic varieties developed in the Philippines will be used in the PNG breeding programme. This programme will use the outcome (results) of the germplasm currently being evaluated in the ICG-SP.

Dwarf x Tall hybrids
The 78 series of Dwarf x Tall hybrids produced during 1992-1993 are being field-tested. Additional four Dwarf and four Tall accessions have been used to develop new progenies for GCA trials.

Research projects/activities conducted

Capacity building

Technical assistance
Since 1994, specialists, supported by COGENT/IPGRI, have provided technical assistance missions to help CCI/CCRI enhance coconut research. These missions included assessing the country's coconut R&D capability, identifying common problems and opportunities for network collaboration, identifying a suitable site for the ICG-SP, evaluating embryo culture laboratories, evaluating germplasm collecting and conservation strategies, assessing the pest risks for the ICG, and assisting in the establishment of ICG-SP.

Training and human resources development
From 1996 to 2002, five local coconut researchers were trained through COGENT/IPGRI on various topics such as coconut germplasm management, collecting and conservation methods, coconut data analysis, computer use, documentation, coconut embryo *in vitro* culture techniques, and the use of the microsatellite kit and dedicated statistical software.

COGENT meetings/workshops
In 1998, a meeting and a workshop were held in PNG, including the 7th COGENT Steering Committee Meeting which was held in Madang. The meeting further endorsed the country, through CCRI, as the host of the ICG-SP.

Research projects
A total of 12 coconut research and development projects have either been completed or are underway in the country, with CCRI as the lead implementing agency.

Financial support and funding

Donor funding support generated by COGENT/IPGRI for the coconut projects in PNG totals US$ 100 475, was mostly from the Asian Development Bank (ADB), and the Department for International Development (DFID). National government counterpart financing for these projects amounted to US$ 295 831, mostly in the form of logistics support by the implementing agency (CCRI).

Results/Outputs and benefits

Improved coconut embryo culture capability

As a result of the COGENT/IPGRI-sponsored coconut embryo culture expert visit and training of CCRI staff, research capacity has been improved. The laboratory facilities have also been upgraded and the culture unit has been improved and now fully-functional. A research officer has also been trained to run the coconut embryo culture laboratory. Other COGENT-funded infrastructure development includes the building of the embryo culture room and procurement of appropriate equipment, acquisition of post-entry quarantine and acclimatization units, and provision of stand-by generator.

Genebank personnel have also been trained on the approved embryo culture protocol and now adopted in practice. The first generations of plantlets using the approved protocol are now planted in polybags in the nursery. In addition, other infrastructure funding by COGENT in support of the ICG-SP has greatly benefited PNG. This includes mainly the recognition of country's role in coconut research and development in the region, and the consequent greater attention from scientific community to invest in PNG coconut programme (e.g. the Centre de Coopération Internationale en Recherche Agronomique pour le Développement or CIRAD, and the Australian Centre for International Agricultural Research or ACIAR) through donor-assisted projects.

ACIAR-funded project on coconut embryo quality studies

The ACIAR-funded project on 'Coconut Tissue Culture for Clonal Propagation and Safe Germplasm Exchange' has been approved enabling PNG to participate in the project. Although the project was originally intended to start in July 2002, project activities, particularly experiments on embryo quality studies, only started in April 2003. The results to date are being reviewed and future directions are being discussed.

Current germplasm maintained at the ICG-SP

In 2003, the ICG-SP held 38 Tall and 11 Dwarf accessions, most of which are national germplasm collections provided by CCI as stipulated in the

MOA establishing the ICG-SP. Since then, more accessions have been collected and conserved in the regional genebank. In 2000, CIRAD, in collaboration with the Secretariat of the South Pacific (SPC) and COGENT, collected coconut germplasm from atolls of Cook Islands, Marshall Islands, Kiribati and Tuvalu. These were cultured at SPC in Fiji and transferred to ICG-SP for *in vitro* culture and eventual conservation. If funds are available, PNG-CCRI will organize a collecting team to visit other germplasm centres of the donor-member countries to collect their designated germplasm.

Planned activities

Site establishment

A new area has been identified and being prepared as part of the PNG's commitment to expand the coconut breeding programme. Major field preparation activities include brushing, felling, drainage and cover crop planting.

Germplasm introduction and establishment

A total of 200 accessions are scheduled to be planted and conserved in the ICG-SP in the next seven years (Table 1). The 7-year development plan and the budget had been submitted to AusAID for possible funding.

Table 1. Schedule of germplasm planting in the ICG-SP for the next seven years

Year	0	1	2	3	4	5	6	7	Total
No. of germplasm	54	75	96	117	138	159	180	200	200
Budget (US$)	1272	1776	2280	2784	3288	3792	4296	4800	4800

Note: *Zero year means germplasm currently conserved in the field genebank at ICG-SP*

Germplasm management

This activity will include *in vitro* culture of imported germplasm, growth and management in culture room until potting and acclimatization stage. Also the poly bag nursery maintenance until the field planting stage.

Field genebank management includes weed control, pest management, drainage and general field upkeep. Income generation from the sale of dry nuts and intercrops is part of the management activities to augment the ICG-Management Fund. The trust account is being organised for the management fund and for future donor funding.

Other planned activities of the ICG-SP

1. Coconut leaf analysis to determine soil nutrient level at ICG
2. Germplasm survey in high risk areas, including the atolls

3. Survey and identification of farmers' varieties
4. Evaluation of Dwarfs for tender nut drink and food production
5. Research and training for the ICG staff and those from the region
6. Conduct of income generation activities for the maintenance of the genebank

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South Pacific

Status of coconut genetic resources research in Samoa

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Introduction

Coconut is the most predominant crop grown in Samoa. Its traditional value and multipurpose uses make it one of the most important crops in the everyday lives of Samoans as an important source of food and cash. In 1996, Samoa exported coconut food products such as coconut cream, copra, copra meal and coconuts, worth SAT 3.598M (US$ 1.3M). The Agricultural Census (1989) stated that 96% of farmers' holdings grew coconuts, which bring to a total land area of 27 692 ha. In Samoa, one of the most important crop mixtures being identified is coconut intercropped with cocoa, the others being crops like banana and taro (Agricultural Census 1999). However, due to price fluctuations of coconuts all around the world, there is a need to upgrade and improve approaches in coconut farming and encourage adoption of new production and processing technologies to enhance farmers' incomes.

Project activities conducted and outputs

Farmer participatory research on the multipurpose uses of the coconut and characterization of farmers' varieties

Under this International Coconut Genetic Resources Network (COGENT)-supported project, farmers' coconut varieties were characterized, documented and conserved on farm. Farmer participatory survey was conducted in Siufaga Savaii where seven varieties were identified and conserved in farmers' fields. These varieties include the Samoan Tall (SMOT), Samoan Tall Samatau (SMOT01), Niu Vai Tall (NVIT), Niu Afa Tall Samoa (NAFT), Niu Lea Dwarf Samoa (NLAD02), Samoa Yellow Dwarf (SYD) and Samoan Tall Siufaga Savaii (SMOT03). A database on these farmers' varieties has also been compiled.

Coconut food recipes

A total of 10 coconut food and five cocktail (beverage) recipes have been compiled and submitted to COGENT for inclusion in the International Catalogue of Coconut Food Recipes.

Coconut-based Farming System (CBFS) as strategies for enhancing farmers' incomes and conserving coconut germplasm

One experimental plot has been established at Nuu Crop Development Centre where intercrops such as banana, guava, taro and taamu are being grown under coconuts. The favourable initial results were used to formulate new research on coconut-based farming system (CBFS).

Television promotional programmes on CBFS and production of posters on value-added products from coconuts

In collaboration with the Televise Samoa Corporation under the 'Atinae Samoa' Programme (Samoan Development Programme), three special episodes on coconut were produced. The episodes, with 15 minutes run time each, are on the following topics: (1) coconut-based farming systems; (2) export potential of coconuts; and 3) the coconut breeding programme at Olomanu Hybrid Seed Garden.

A poster was also prepared and printed to promote the potential value-added products made from coconuts. Copies of the poster were distributed to different government offices, schools, manufacturing agencies and during special events such as the Coconut Day and the World Food Day.

Compilation of coconut literature

A list of publications on coconuts has been compiled from several sources such as the Nelson Memorial Library in Apia, University of the South Pacific, Alafua Campus Library, the National University of Samoa Toomatagi and others, which could be used by researchers in finding relevant information on coconut. The compiled list includes the following publications:

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Future research and development strategies

The Ministry will continue to conduct surveys to identify and characterize new ecotypes. Nuts of the new ecotypes will be collected for multiplication and conservation in Olomanu Hybrid Seed Garden. In addition, two new CBFS plots will be established on farmers’ field.

South Pacific

Status of coconut genetic resources research in Tonga

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Introduction

Coconut is an important crop which has supported the livelihoods of the Tongan people for hundred of years. Lately, Tongan coconut farmers have been suffering from declining productivity and unstable markets of copra and coconut oil, traditional products derived from the coconut. Tongan farming systems are basically multi-storied and agro-forestry based, with root crops and other crops as the common intercrops. Farmers in the country are willing to learn and adopt new and more efficient farm management strategies and approaches to improve their existing coconut-based farming system.

Research activities conducted and outputs

Collecting and conservation of coconut germplasm from Vava'u, Ha'apai and the Niua Islands

Tonga has a coconut germplasm collection that was started six years ago. Part of the collecting activity was carried out during Phase I of the Asian Development Bank (ADB)-funded project entitled, 'Collecting, conserving and characterizing coconut genetic resources in eight Asia Pacific countries', which was coordinated by the International Plant Genetic Resources Institute's International Coconut Genetic Resources Network (IPGRI/COGENT). The accessions collected came mainly from the main island of Tongatapu. However, there is a need to explore and collect the coconut genetic resources of the other islands, particularly those in the north such as Vava'u, Ha'apai and the Niua Islands.

To date, four ecotypes, namely: Niu Kafa, Niu Vai, Niu 'Utongau, Niu Matakula and Niu Talokave, have been collected and characterized from Vava'u, Utongau and Ha'apai. Data collected have been submitted to COGENT and entered into the International Coconut Genetic Resources Database (CGRD). These ecotypes have also been planted in the genebank in Vaini Research Station for conservation and further study.

Promoting germplasm conservation of Tonga's coconut diversity through increased farm productivity

This COGENT-assisted project aims to: (1) identify and describe the multipurpose uses of coconut, and the local ecotypes grown by farmers for these uses; (2) develop strategies for product utilization and to add value to products from local varieties; (3) quantify marketable products from coconut and to evaluate and promote technologies for commercializing these; and (4) evaluate coconut-based farming system technologies to enhance germplasm conservation and farmers' incomes.

Farmer participatory survey to identify multipurpose uses and varieties suitable for these uses and to promote germplasm conservation

The main purpose of this project component was to characterize, document and conserve farmers' coconut varieties. Farmer participatory survey was conducted in Tongatapu where eight varieties were identified and conserved in farmers' fields. These varieties include: Niu Vai, Niu Kafa, Niu Matakula, Niu Leka, Niu Ta'okave, Niu Loholohotaha, Niu Mea and Tonga Talls.

During the participatory rural appraisal workshop, it was also found out that one of the main problems of smallholder farmers was the limited income-generating opportunities from coconut primarily caused by irregular supply of raw materials and lack of markets (both domestic and overseas). The irregular supply of raw materials was caused by low crop productivity due to ageing palms, animal damage, seasonal productivity, saltwater intrusion (sea spray) and water logging. Another major contributor to low productivity was the close and dense planting of coconut pamls resulting in competition for nutrients and moisture, as well as difficulty in maintenance.

Evaluation of coconut-based intercropping technologies

Farmers preferred the Tonga Tall variety compared to others because of its capacity to accommodate intercrops due to its greater spacing requirement. Based on COGENT's recommended strategy, farmers planted squash, kava, watermelon, vanilla and root crops as intercrops with coconut primarily for their export market potential. The project found out that intercropping can be promoted to more farmers to further enhance food security and expand export markets.

South Pacific

Status of coconut genetic resources research in Vanuatu

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Introduction

Vanuatu, formerly called New Hebrides, is an archipelago located in the Southwest Pacific Ocean between the Solomon and Fiji Islands. It consists of some 80 widely dispersed islands between the Torres Group (13°S) to the uninhabited Matthew and Hunter islets (22°S). As in most of the Pacific Island countries, coconut is widely planted and used by the rural populations for food and for numerous other domestic purposes. The production of copra started in the 1870s and was the mainstay of Vanuatu's economy until the 20th century. Even when world demand and prices for the product declined, copra remained as the most important export commodity of the country, with around 30 000 metric tonnes exported annually. Coconut is grown in an estimated 90 000 ha, representing nearly 60% of the total cultivated area in the country.

On the southeast coast of Espiritu Santo Island, near the village of Saraoutou, a coconut research station was established in 1962. Up to 2001, the station was managed by the French research organization Institut de Recherches pour les Huiles et Oléagineux (IRHO), which became the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) in 1985. The Saraoutou Research Centre is now called the Vanuatu Agricultural Research and Technical Centre (VARTC).

Researchable problems and opportunities

Tolerance to coconut foliar decay

When the Saraoutou Station was created, the main objective of its research work was to increase coconut productivity through agronomic and genetic improvement, particularly by developing high-yielding and suitable hybrids to replace the ageing established local varieties. A number of exotic varieties were planted in a field genebank, but they quickly started to succumb to a previously unseen wilt of unknown aetiology, while the local Vanuatu Tall (VTT) variety, remained unaffected. This new wilt was named 'coconut foliar decay' or CFDV, a viral disease transmitted by the insect vector *Myndus taffini* (Julia 1982). Following this discovery, tolerance to CFDV was decided as the main criterion for selecting and developing coconut planting materials for Vanuatu.

Enrichment of VARTC field genebank and conservation of local coconut genetic resources

As the main source of CFDV tolerance, the use of the local Vanuatu Tall was the central strategy for the coconut breeding programme. Before the International Plant Genetic Resources Institute's International Coconut Genetic Resources Network (COGENT)-sponsored projects started, the genetic diversity of local coconut genetic resources in Vanuatu was not properly assessed and conserved. There was also a need to conduct a survey to identify the different uses of coconut, other than copra. At that time, the *in situ* management of coconut genetic resources by farmers was still unexplored.

Improvement of coconut-based farming system

With the recent drop in world copra prices, it is urgent to find ways to improve smallholders' incomes. The coconut groves are senescent and occupy large areas. The planting of precocious, high-yielding cultivars created through research can optimize the landuse. However, the dissemination of the improved planting material is expensive due to the distant locations of the cultivated areas, and the difficulties and high cost of transport around the archipelago. Diverse associations of coconut with other crops have been observed during farmers' participatory surveys. The performance, the sustainability and market opportunities of such associations must therefore be assessed.

Diversification of coconut uses

Even if a wide range of coconut by-products and uses have been observed at rural household level, very few are marketed in the urban areas or exported. The industrial processing for grated coconut, canned coconut milk and other similar products is not profitable in Vanuatu due to the limited domestic market, expensive inputs, high transport and labour costs. Nevertheless, the marketing of fresh products (tender and mature coconuts) and small-scale processed products (e.g. virgin oil) could be developed. The use of copra oil as biofuel for vehicles shows promise. Projects for the electrification of remote areas by using copra oil powered-generators are also being explored.

Research and training activities conducted in the country

During the last 10 years (1994-2003), the Department of Agriculture and Rural Development (DARD) and VARTC have actively participated in the different projects and training activities coordinated by COGENT, which are as follows:

Evaluation of selected coconut cultivars planted in farmers' fields in Vanuatu

The agronomic performance of three improved coconut cultivars, distributed to farmers during the implementation of the Coconut Development Project (CDP) between 1982 and 1993, were evaluated through COGENT's Asian Development Bank (ADB)-funded project. For this purpose, observations were conducted on farmers' plots and results are presented in Table 1.

Table 1. Comparative performance of three cultivars in Vanuatu for yield and copra processing

Characteristics	VTT	VTT x RIT	VRD x VTT
Average annual yield under farmers' field conditions as evaluated from 1994 to 1997 (tonnes)	2.0	2.6	2.2
Average copra content per nut as measured from 1994 to 2000 (in grams)	199	258	134
Percentage of oil in albumen dry matter	66.2	66.0	65.4
Percentage of water in fresh albumen	47.4	50.8	55.8
Number of nuts needed for one tonne of copra	5555	4360	7600
Time to process these nuts (comparison with VTT x RIT)	26.5 hours (+ 11%)	24 hours	37 hours (+ 55 %)
Quantity of copra obtained from one tonne of fresh kernel by hot air drying process (in kg)	467	447	415

Legend: *VTT = Vanuatu Tall RIT = Renelle Tall VRD = Vanuatu Red Dwarf*

Collecting, evaluation and characterization of coconut genetic resources in Vanuatu

The main purpose of this ADB-funded project was the evaluation and the *ex situ* conservation of the genetic diversity of local coconut genetic resources. Fourteen sites located in 10 different islands of the archipelago were surveyed. Two hundred nuts each of the 12 populations were collected. Eighteen variants showing special characteristics (spicata form, unique nut colour, etc) were also collected but with smaller sample size. They were all established in VARTC field genebank (Labouisse and Sileye 2001). As of 2003, the local germplasm collection of VARTC consists of 20 populations of Vanuatu Tall and the Vanuatu Red Dwarf (VRD).

Enhancing farmer incomes and germplasm conservation through coconut- based farming system and identification of varieties for multipurpose uses

This International Fund and Development (IFAD)-funded project consisted of three components:

Component 1: Farmer participatory surveys

During the period July 1998 - December 2000, eight participatory rural appraisal surveys (PRAS) were conducted on seven different islands gathering substantial information about local names and uses of coconuts, and different coconut-based farming systems. An average of 11 distinct types (or variants) of coconuts per village were identified by the farmers with numerous by-products and uses documented (Table 2). Some variants are associated to specific uses (Lahva and Labouisse 2000). This component is closely linked with the project on characterization and conservation of local cultivars. Samples of leaves of some collected populations were analyzed with the microsatellite kit developed by CIRAD (Baudouin and Lebrun 2002) to assess the genetic diversity within and between the populations.

The results of the PRAs were presented and discussed in a journal article by Labouisse and Caillon (2001). A set of three posters in bislama (Vanuatu's official language) was prepared and posted in the rural communities in order to make them aware of coconut genetic resources conservation strategies.

Component 2: Feasibility of coconut based intercropping systems for promoting coconut germplasm conservation through use

During the PRAs, the associations between coconuts and others crops have been documented. The socioeconomic survey on marketable crops produced in association with coconuts shows the opportunities and constraints of the different crop varieties and present some data on costs and returns (Bule 2000). The survey indicated that *Xanthosoma sagittifolium* and *Musa* sp. are the most frequently cultivated crops under coconuts, while Kava (*Piper methysticum*) is shown to be the most profitable. It was also identified that high transportation costs from farms to markets is the main productivity constraint.

Component 3: Evaluation of the improved cultivars used by farmers in Vanuatu for processing

Under the ADB-funded Project, the agronomic performance of three cultivars, (improved VTT, VRD x VTT hybrid, VTT hybrid x RIT hybrid, were assessed in farmers' fields (Labouisse and Buletare 1997). Under

Table 2. List of the common uses of and products from the coconut as surveyed in the villages of Vanuatu
(Source: Lahva and Labouisse 2000)

Coconut part	Uses and products
Whole palm	• Land marking • Garden ornamentation • Cattle shade
Roots	• Medical uses
Trunk	• Building material and furniture (post, plank, part of canoe) • Support for plants (yams, vanilla) • Medical uses (bark)
Leaves	• Handicrafts (hat, mat, fan, broom, baskets, hoop net) • Building material (roof, walls) • Support for plants • Fuel and light (torch) • Filter for kava
Whole fruit	• Ceremonial uses (wedding present, customary exchanges)
Husk	• Rope for building and for canoe • Container, support and protection for plants • Fuel • Abrasive
Shell	• Handicrafts (container, cup, spoon) • Kava cup • Fuel
Water	• Beverage • Medical and ’magic‘ uses (excipient)
Albumen	• Food • Copra
Milk	• Food • Medical uses (excipient)
Oil	• Food • Oil for human body and hair conditioning • Fuel (for lamp)

the IFAD-funded project, the quality of the fruits of these three varieties was also evaluated for copra production and processing (Lahva and Labouisse 2000). Results showed that the hybrid VTT x RIT outperformed the two other varieties in terms of nut yield and copra production (Table 1).

Contribution to the Coconut Genetic Resources Database (CGRD)

The entries of Vanuatu in the International Coconut Genetic Resources Database (CGRD) comprise of 60 living accessions. In addition, morphometric and passport data of 12 accessions which do not exist anymore (due to cyclones or felling) have also been recorded and included in the CGRD.

Training activities sponsored by COGENT

Two regional training courses were held in Vanuatu while five Vanuatu researchers were sponsored by COGENT to undergo staff development training on topics such as standardized research technique in coconut breeding (STANTECH), coconut germplasm collecting and conservation, farmer participatory research, computer use, documentation and data analysis, and technical writing and seminar presentation (Table 3).

Table 3. List of COGENT-sponsored training courses with participating Vanuatu researchers

COGENT training courses organized in Vanuatu	No. of trainees/ participating countries
Regional STANTECH course for South Pacific (VARTC, 6-13/8/1996)	9 / PNG, Solomon Islands, Tonga, Fiji, Kiribati, Vanuatu
STANTECH training course on collecting and management of coconut genetic resources (VARTC, 29/6-10/7/1999)	4 / Kiribati, Cooks Islands, Marshall Islands, Tuvalu
COGENT training courses organized outside Vanuatu	**Participating Vanuatu researchers**
Coconut collecting and conservation course (PCA, Philippines, 1-12/9/1997)	Godefroy Buletare
Farmers participatory research on coconut diversity (Taveuni Coconut Centre, Fiji, 24-28/3/1998)	Pierre-Chanel Watas, Jeffrey Lahva, Jean-Pierre Labouisse
Computer use, documentation and data analysis course for South Pacific (SPC, Suva, Fiji, 3-7/8/1998)	Godefroy Buletare
Technical writing, seminar presentation and proposal writing course (PCA, Philippines, 30/8-3/9/1999)	Jeffrey Lahva
Coconut data analysis training course (PCA, Philippines, 6-10/9/1999)	Jeffrey Lahva
Establishment and management of field genebanks for conservation and use (PSGT, Malaysia, 28/9 – 10/10/1999)	Tiata Sileye

Other activities carried out within the framework of COGENT

1995 - Participation in the finalization of the STANTECH Manual (Santos *et al.* 1996) in Manado, North Sulawesi, Indonesia.

1996 - Pacific Projects review of Coconut Genetic Resources Network and Asia Pacific (CGRNAP) at VARTC.

1996 - Participation in the COGENT Steering Committee in Merida, Mexico as a representative of the Pacific region.

1999 - Participation in the COGENT consultancy on coconut collecting strategy (Bourdeix *et al.* 1999).

2000/2001- Appointment of VARTC as the implementing agency for the ADB-CGRNAP project on 'Coconut germplasm collecting, characterization and conservation in Cook Islands, Kiribati, Marshall Islands and Tuvalu' (Labouisse and Bourdeix 2003).

2002 - Participation in the preparation of the International Catalogue of Conserved Coconut Germplasm and Farmers' Varieties.

Activities supported by other donors

Conservation and observation of exotic germplasm

Exotic varieties which are susceptible to CFDV can be conserved in VARTC field genebank by removing, within a radius of about a hundred meters, all stumps of *Hibiscus tiliaceus*, the breeding host of the CFDV vector. Through the Pacific Regional Agricultural Programme (PRAP) project, the exotic germplasm of VARTC have been fully rejuvenated by hand pollination between 1992 and 2000. To date, the collection comprises of 14 distinct Tall and 13 Dwarf varieties imported from different countries of Africa, America, Asia and Pacific. Growth characteristics, yield, fruit component analysis are regularly recorded. Observations were also done in 1999 on the tolerance of Dwarfs to strong winds (Figure 1).

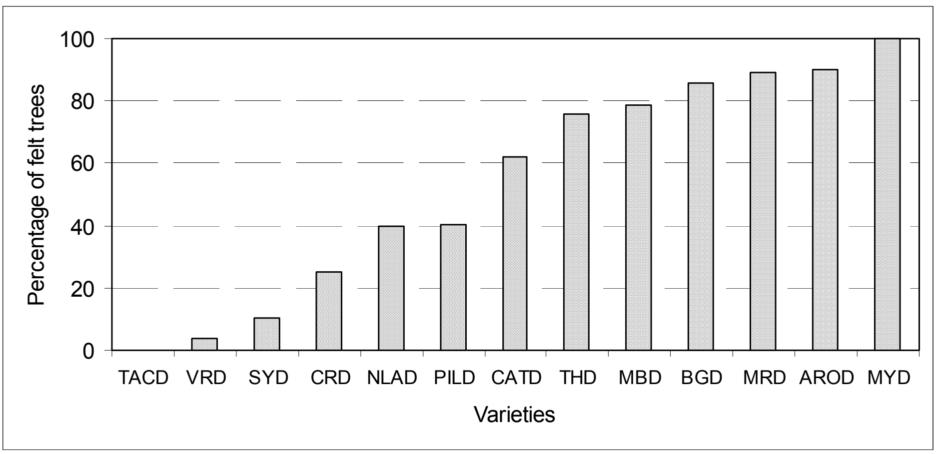

Figure 1. Damage inflicted by cyclone Dani (January 1999) on the different Dwarf varieties (aged 15) in the VARTC genebank.

Improvement of coconut planting materials for Vanuatu

Three cultivars were selected for propagation in Vanuatu for their tolerance to CFDV. These include the improved Vanuatu Tall, the VRDxVTT and the VTTxRIT hybrids.

The improved Vanuatu Tall, obtained from several cycles of mass selection, has an average copra yield of 2.2 t/ha/year and a copra content of 195 g/nut. It is completely tolerant to CFDV and can be easily multiplied by farmers.

The VRD x VTT hybrid line, tolerant to CFDV, is produced in seedgardens at Saraoutou Station and was released to farmers between 1986 and 1996. In spite of its high-yielding potential of 3.4 t/ha/year (as recorded in station trials), its dissemination was discontinued due to its low germination rate in the nursery, a low copra content (154 g) and the frequent dropping of immature bunches.

The VTT x RIT hybrid is the most promising with an average yield of 2.6 t/ha/year and a high copra content of 237 g/nut. The first lines of this hybrid showed very slight susceptibility to CFDV. However, the tolerance has been improved by using, as female parent, several self-pollinated progenies of RIT which show no symptoms of the disease. The VTT and the VTT x RIT hybrid, with good nursery and cultivation practices coupled with an ideal climate, start to bear flowers 30 months after planting, which is remarkable for Tall cultivars.

PRAP - PDICC Project

From 1989 to 1999, with the financial support of the European Union (EU) and the French Ministry of Foreign Affairs, and the technical assistance of CIRAD, VARTC implemented the Production and Dissemination of Improved Coconut Cultivars (PDICC) project in the framework of the PRAP. Eight countries (Fiji, Kiribati, PNG, Tonga, Samoa, Solomon Islands, Tuvalu and Vanuatu) were associated with this regional programme. The objectives of the PDICC project were:

1. To improve the potential of coconut production by increasing the choice of hybrid coconut cultivars in the South Pacific Region. A wide range of hybrids was created and the performance assessed in experimental trials established at VARTC. Before 1999, the project also supported the maintenance and the data collecting of VARTC coconut germplasm; and
2. To improve the quality of planting materials disseminated to farmers from the seedgardens of the participating countries. Technical assistance and training were provided to these countries for seedgarden management, coconut breeding and coconut genetic resources management.

Under the project, 39 new hybrid crossings were made by hand-pollination and eight trials were successfully established in Saraoutou Station between 1992 and 1999. This represents a total area of 57 hectares with approximately 9000 palms under individual observation. Each of the first seven trials included hybrids created by crossing diverse Dwarf cultivars with a Tall cultivar native to the region (i.e., Rennell Tall (RIT), Tonga Tall (TONT), Rotuman Tall (RTMT), Kiribati Tall (KIT), Gazelle Peninsula Tall (GPT), Samoan Tall (SMOT) and Markham Valley Tall (MVT)). In the eighth trial, six different Tall cultivars were crossed with RIT. For each trial, the following data were gathered: rate of germination, growth in the nursery, growth in the field (young age), flowering, yield, fruit component analysis, oil content, stem measurements, resistance to cyclone and susceptibility to diseases.

For copra yield, the hybrid MRD x RIT showed good performance in all the trials, producing about five tonnes of copra/ha when six years old. The hybrids MYD x RIT, BGD x RIT, MRD x TONT and MRD x RTMT also showed good potential. Some of the varieties also showed some promise on the tolerance to cyclones (Labouisse 2002).

Study of *in situ* management of coconut genetic resources

With the support of CIRAD and the Institut de Recherche pour le Développement (IRD), a three-year study in the framework of a PhD thesis was conducted since 2001 on *in situ* management of coconut genetic resources by farmers in Vanuatu (Caillon 2001). The study aims to further understand the biological and sociological processes that build the diversity of a crop system.

The study was performed in Vanua Lava in the north of Vanuatu. The farmers themselves distinguished the existing variants in Vanuatu Tall variety according to some specific morphological traits, production characteristics or particular origin. The average number of variants identified by village in Vanua Lava is 30, far above the number found during the IFAD-funded project, which was attributed to a longer and more intensive survey (Caillon and Malau 2002).

Variants are being described according to the STANTECH Manual. Statistical analyses done on 105 individuals showed that the most discriminant characters are those related to the description of fruit components. The results of molecular analysis using 14 microsatellites performed on 69 coconut leaves collected in Vanua Lava from 12 variants revealed that the whole population is distinct from the rest of Vanuatu and other Pacific countries. However, this technique is inadequate to differentiate the variants except for one (a Tall with yellow fruits). As the sampled population is small (two to eight individuals per variant), additional analyses have do be done to confirm these initial results.

Study on coconut-based farming systems

Since 2002, a study on the methods of assessment of performances and sustainability of associations of staple crops with old coconuts has been undertaken on the island of Malo in the framework of a PhD thesis sponsored by CIRAD (Lamanda *et al.* 2003).

Interpretation of significance or impact of output

The use of participatory approach for the assessment of coconut diversity in Vanuatu was very fruitful. Several coconut variants were identified and traditional uses discovered. VARTC's collection has been enriched with populations of Vanuatu Tall collected in different environments.

The improved VTT represents a significant advancement compared to ordinary VTT, with a better yield but, above all, a higher copra content which reduces the labour needs for copra processing. The hybrid VTT x RIT is also promising but its utilization by farmers is impeded by the high cost of transportation of nuts or seedlings within the archipelago. Contrary to improved VTT, it cannot be reproduced by farmers.

The results of the PRAP trials constitute a database of great value for the research and extension services within the region. These results will also benefit other Pacific countries which would be advised to reproduce the best crossings by using their own germplasm and seedgardens. Unfortunately, these hybrids would not be disseminated to Vanuatu farmers because of their susceptibility to CFDV.

Future research and development activities in coconut

Maintenance and observations of VARTC germplasm

The recently collected populations of Vanuatu Tall will be observed and the most interesting and promising ones could be used for further genetic breeding programme. Besides potential copra yield, the characteristics of the fruits for processing will be assessed.

Maintenance and dissemination of the results of PRAP-PDICC hybrids trials

Due to the biological cycle of the coconut, the performance assessment of a hybrid could only be undertaken about 9-10 years after field planting. Therefore, the evaluation of the first seven trials established at VARTC would only be done by 2006 although the financial support of the EU ended in 1999. Due to the regional significance of these trials, VARTC needs to source external funds for the maintenance and full evaluation of these trials until 2006.

Improvement of coconut-based farming systems

With the objective of improving the effectiveness and profitability of coconut-based farming systems (CBFS), the evolution of the different CBFS in Malo Islands is being studied. Likewise, the assessment of performance of the association of ageing coconut with other crops requires further research on agronomy, plant protection and physiology of coconuts and other crops (fruit trees, rootcrops, kava *Piper methysticum*, legume trees, etc) and on farm economy. The results of these studies will enrich CBFS technologies and, hopefully, provide increased benefits to resource-poor coconut farmers and their households.

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