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ARTICLE

Contribution of the institutions in the Northern region of Brazil to the development of plant cultivars and their impact on agriculture

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Abstract - *This paper describes the development of breeding programs in northern Brazil and their main impacts on agriculture. Their contribution to the breeding of the species palm oil, acai fruit, cacao, cupuaçu, guarana, tomato, camu-camu, cocona, peach palm, and rubber was laid out in detail. Advances in breeding programs of institutions such as Embrapa, Ceplac, Inpa, and Universities require investments in infrastructure and in human and financial resources to ensure continuity and efficiency in economic, social and environmental gains. The improvement of native species, the main focus of the breeding programs of the institutions in the Northern region of Brazil, is a form of exploiting the Amazonian biodiversity for the benefit of society. Therefore, policies to foster research institutions should be a subject of deliberation and action of the scientific and technological community in Brazil.*

Key words: *Plant breeding, Amazon region, native species.*

INTRODUCTION

Breeding is largely responsible for the excellent performance of agriculture today, with gains in productivity, resistance to biotic and abiotic factors, and the supply of new market products. In the Northern region of Brazil, breeding programs have contributed significantly to the development of new cultivars, although the number of specialists in subfields of agricultural science such as breeding is still marginal. Only 4% of all plant geneticists in Brazil work in this region (Teixeira 2009), showing that a greater investment is needed to prevent brain drain. The low retention of specialists in the region is a limiting factor for the development of new cultivars, mainly of native species. The following research institutions maintain breeding programs in the region: Embrapa (Brazilian Agricultural Research Corporation), Ceplac (Executive Planning Commission of Cocoa Farming) and the Inpa (National Institute for Amazonian Research). The universities that offer postgraduate courses in areas related to plant breeding contribute significantly to complement the work of the regional breeding programs, e.g., UFAM (Federal University of Amazonas) and UFRA (Federal Rural University of Amazonia) in the state of Pará.

The cultivars of oil palm (*Elaeis guineensis* Jacq.) developed by Embrapa are an example of impact on agriculture. Until the late 1980s, commercial plantations in Brazil were grown exclusively from seed imported from Africa, Asia and Central America. In the same decade, a breeding program was initiated by Embrapa Western Amazon (Manaus, Amazonia) and the first cultivars of high-yielding *E. guineensis* were selected in 1992, to meet part of the national demand for seed (Barcelos et al. 2000). After the spread of fatal yellowing (FY) of oil palm,

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a lethal disorder of unknown cause, the breeding program of Embrapa adopted a strategy of developing and selecting interspecific hybrids between *E. guineensis* and the native species *E. oleifera* (caiaué). The first cultivar bred in the interspecific hybridization program was the recently recommended BRS Manicoré, currently the only possibility for the viability of oil palm cultivation in areas of FY incidence (Cunha and Lopes 2010). This cultivar is grown on about 3,000 ha in the state of Pará, although an increase is expected in the coming years, with the replanting of oil palm plantations decimated by FY, as well as in the plantations expanding into the surroundings.

The Executive Planning Commission of Cocoa Farming - (Ceplac) has played a significant role in the development of agriculture in the region. The planting of hybrid cocoa varieties on a total are of approximately 124,600 ha (IBGE 2012) has consolidated the formation of two cacao production regions, in Pará and Rondônia.

The Institute for Amazonian Research (INPA), comprising the Active Germplasm Bank of peach palm, introduced thornless peach palm (*Bactris gasipaes* Kunth*, Palmae*) races in selection programs in several Brazilian regions. Populations from Yurimáguas, Peru and from Benjamin Constant, Amazonia, Brazil, represented the basis for the first progeny selections in the Northern region and were included in different peach palm breeding programs.

This paper gives an overview of the evolution of breeding programs of research institutions in the Northern region.

PLANT BREEDING PROGRAMS IN THE NORTHERN REGION OF BRAZIL

Embrapa

Embrapa, a public company subject to private law of the Ministry of Agriculture, Livestock and Supply (MAPA), was created on April 26, 1973. The company's mission is to facilitate the introduction of research, development and innovation results for sustainable agriculture with a view to benefit the Brazilian society. The Company consists of a system of Administrative Units, headquartered in Brasília/DF, and of Research and Service Units, also called Decentralized Units (DUs), distributed across the different regions of the country. The DUs of the Northern region, focused on plant breeding programs, are located as follows: Embrapa Western Amazon in Manaus, Amazonas; Embrapa Eastern Amazon in Belém, Pará; Embrapa Rondônia in Porto Velho, Rondonia; Embrapa Acre in Rio Branco, Acre; Embrapa Amapá in Macapá, Amapá and Embrapa Roraima in Boa Vista, Roraima.

African oil palm (*Elaeis guineensis* Jacq.)

In 2010, the world production of palm oil was 45.1 million t and the cultivation area reached 15.0 million ha (FAO, http://faostat3.fao.org/home/index.html), indicating that the species is still the primary source of vegetable oil. In the early 1980s, the Ministry of Agriculture laid a solid technological foundation, by the creation of the National Oil Palm Research program, through Embrapa, designated to provide the country with expertise to support and ensure the expansion of the national oil palm cultivation, aside from the initiative of local seed production according to international market quality standards. The merit of this impulsion was personnel training and the introduction of newly developed plant material, resulting in the achievement of domestic self-sufficiency in the production of high quality seed.

The oil palm breeding program of Embrapa Western Amazon developed two types of cultivars: intraspecific hybrids between African parental varieties of *Elaeis guineensis* (Jacq.) (*Dura* and *Pisifera*) called *tenera* and an interspecific hybrid between the American species *E. oleifera* and the African species *E. guineensis*. Seven tenera hybrids were selected from crosses between oil palm parents *Dura* (source Deli) and *Pisifera* (source La Mé): BRS C2001, BRS C2301, BRS C2328, BRS C2501, BRS C2528, BRS C3701, and BRS C7201. The main characteristics of these intraspecific hybrids are an average trunk growth rate of 45 cm yr^{-1}; a palm bunch yield of 20-30 t ha^{-1} yr^{-1}, depending on the management; an extraction rate of mesocarp oil of around 22% and average palm oil yield of 4-6 t ha^{-1} yr^{-1}, and an palm kernel extraction rate of 2.5 - 3% and production of 0.63 - 0.75 t ha^{-1} yr^{-1} of palm kernel oil. An oil production of 6 t ha^{-1} yr^{-1} has been reported from plantations in the state of Pará. In the high season, usually in October or November, the year-round production can peak in a monthly yield of 14-15% of the annual production and can reach 5% in the low phase, usually in February or March, depending on the rainfall distribution in the region (Cunha et al. 2007).

BRS Manicoré is an interspecific hybrid (ISH) of the female parent *E. oleifera,* Manicoré source and male *Pisifera* parents of La Mé oil palm (LM2T and LM10T). This cultivar is recommended for areas of FY incidence and has been adopted by all palm growers in these areas in Pará. The vertical trunk growth of BRS Manicoré (17 - 24 cm yr^{-1}), lower than that of the cultivars of tenera oil palm (45 - 60 cm yr^{-1}), should extend the life of commercial plantings of this variety. The production of palm fruit bunches (25 - 30 t $ha^{-1}yr^{-1}$) is similar to the oil palm cultivars tenera, although the oil extraction rate is lower than 18 - 20%, resulting in a palm oil production of 4.5 - 6.0 t ha^{-1} yr^{-1} (Cunha and Lopes 2010).

The impact of genetic improvement on oil palm production revitalized the crop cultivation in the region. BRS Manicoré allowed the replanting of areas decimated by FY in the surroundings of Belém (Benevides, Santa Izabel, Santo Antônio do Tauá, Moju, etc.), which had been abandoned, leading to the resumption of production activity and income and job creation in the region. Within 20 years, it is estimated that the ISHs will come to be the predominantly used plant material in Brazil and in other South American countries (Colombia, Peru, Ecuador, and others), where oil palm cultivation is economically and socially relevant. This shows the importance of investment in research of Embrapa and the great strategic value of *Elaeis oleifera* germplasm, native to the Brazilian Amazon, well-represented in the Active Germplasm Bank of Embrapa Western Amazon, in Manaus, Amazonia.

Acaí palm (*Euterpe oleracea* Mart.)

The acai palm, native to the Amazon, produces a staple food for local populations, especially of riparian and small producers, who extract a drink from acai fruit. The species also constitutes the main raw material source of the palm heart agribusiness in Brazil. Acai occurs naturally mostly in wetlands and marshy areas of the Amazon estuary, on an estimated one million ha, and rather sparsely in upland forests. The demand for acai fruit has grown significantly since 1994 due to the propaganda for the high nutritional and energetic value of the acai drink, outgrowing regional limits to conquer national and international markets. The annual growth rates of the domestic and international acai pulp markets are estimated at 30% and 16%, respectively (Nogueira et al. 2005), with a significant increase in the area of acai plantations since 1994 (no records), reaching 35,000 ha in 2004 (Santana et al. 2008).

In the 1980s, Embrapa Eastern Amazon in Belém, Pará, initiated an acai breeding program based on three species of the genus *Euterpe* (*E. oleracea* Mart., *E. precatoria* Mart. and *E. edulis* Mart.). After three cycles of massal selection of *E. oleracea* germplasm, this work resulted in the establishment of the first cultivar, BRS Pará. In the first cycle, acai palm trees were collected from natural populations of the Amazon estuary and 134 mother plants were selected for low height of the 1st bunch, short internode distance and increased mesocarp thickness, to constitute an acai germplasm collection of Embrapa Eastern Amazon. In a second selection cycle of these plants, beginning with the evaluation and lasting for three years (1996/1997/1998), 25 plants were selected (for a yield of over 16 bunches plant^{-1} yr^{-1}, 25 kg plant^{-1} yr^{-1} of fruits and for purple fruit), from which 750 trees were derived and planted in an upland area in Santa Izabel, PA. Selection in the third cycle, before flowering (3rd year after planting), was for tillering and vigor. Plants with inferior development and no tillering (single stem) were identified and eliminated to allow open-pollinated intercrosses, among desirable plants only. The seeds used for the release of BRS Pará were produced on this latter field, which was transformed into a seed production area (SPA) or improved population (Oliveira et al. 2004, Oliveira et al. 2008).

The cultivar BRS Pará has been used to increase the upland areas of acai in the state of Pará The main features are: earliness (1st fruiting three years after planting); high yield - 3 t ha^{-1} in the first 2 years, increasing to 4 t after 5 years, expected to increase to 6 t in the 6th; 8 t in the 7th and 10 t in the 8th year, high pulp yield (15 - 25%, with an average of 20% edible part per fruit). The earliness can anticipate the economic return on investment into the crop by 40% (Oliveira et al. 2004).

Improved seeds have been purchased by producers from States in the Amazon region and in all other regions of Brazil, e.g., São Paulo, Paraná, Bahia, and Rio de Janeiro. In the Amazon region, demand and sales are highest in Pará, Tocantins and Maranhão. It is estimated that BRS Pará is being grown on an area of over 13,000 ha in Brazil. Of this total, approximately 7,000 ha are in the production phase, with an economic impact of more than $ 1.28 million, a relatively low value since the plantations are in the initial phase of production (Santos et al. 2011).

Planting acai palm for fruit production in upland areas allowed the rehabilitation of areas previously considered degraded (grassland, abandoned pastures, etc.), while providing greater soil protection. The traditional and improved acai palm is predominantly planted in anthropized areas and stimulates no further deforestation. Moreover, the producers are motivated to stay in the region, due to the higher farm profitability and the creation of direct and indirect employment as well as generation of foreign exchange, particularly in the state of Pará

Guarana (*Paullinia cupana Kunth* var. *sorbilis* (Mart.) Ducke)

Guarana is a shrub native to the Amazon, which has been used for centuries by indigenous civilizations because of certain stimulating and medicinal properties. Its cultivation occurs exclusively in Brazil and the producer states are Amazonas, Pará, Acre, Rondônia, Mato Grosso, and Bahia. The crop is cultivated on an area of 13,980 ha, producing 3739 t of dried seeds and a yield of the order of 354 kg ha^{-1} based on the harvested area, corresponding to 75% of the planted area (IBGE 2012). In the Amazon region, the planted area increased from 4,602 ha in 2000 to 6,708 ha in 2010. The main guarana diseases are anthracnose caused by *Colletotrichum guaranicola* and oversprouting, caused by the fungus *Fusarium decemcellulare*.

The guarana breeding program of Embrapa Western Amazon, in the state of Amazonas (AM), began in 1976 with the phenotypic selection of superior mother plants on farms and on an experimental field of Embrapa in Maués, AM. Progenies were tested on experimental fields of Embrapa in Manaus and Maués, evaluating the phenotypic variability. Concomitantly, in the breeding process, progenies of bi-parental crosses and of self-pollinations were tested. In the beginning of the 1980s, the work was directed to clone selection for superior plants evaluated in experiments of progeny tests and on commercial plantations, by cloning of stem cells. Clone competition experiments were used for selection and recommendation of cultivars with a yield of more than 1.0 kg plant^{-1} yr^{-1} of dry seeds, wide adaptability, good stability, tolerance to major diseases (anthracnose and oversprouting) and better chemical quality of seeds (high caffeine content). The first two recommended clonal cultivars were BRS-Amazonas and BRS-Maués; followed by BRS-CG372; BRS-CG648; BRS-CG189; BRS-CG505; BRS-G610; BRS-CG612; BRS-CG 850; BRS-CG882; BRS-CG608; and BRS-CG611 (Nascimento Filho and Atroch 2002). Eighteen clonal cultivars have altogether been developed by the breeding program, most recently BRS Marabitana and BRS Saterê. The advantages of these cultivars are a yield of over 1.0 kg of dry seeds per plant (compared to the regional average of 0.2 kg plant^{-1} of dry seeds) and anthracnose resistance. Guarana, as a crop of regional significance, contributes greatly to the retention of workers in rural areas and to employment generation. The higher yield of new plantations reduces the demand for new expansions, decreasing the impact of deforestation on the rainforest and in compliance with the productive capacity of small farmers (Nascimento Filho et al. 2009a, 2009b).

Cupuaçu (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.)

In the Northern region, cupuaçu is one of the most sold native fruits, with excellent market opportunities for the very pleasant-tasting fruit pulp and for the seeds used in a chocolate-like product, called cupulate (Nazaré et al. 1990), or in the cosmetic industry. The crop gained economic importance in the 1970s, initially in the state of Pará, where it was used as an alternative to occupy areas of black pepper decimated by Fusarium. In the region, the crop is grown on around 30,000 ha, mainly in Pará, with 12,000 ha (SAGRI, http:// www.sagri.pa.gov.br/documentos/). This fruit tree is also promising for other Brazilian states and Bahia is the main producer outside the Northern region.

The cupuaçu breeding program is developed by a network of research institutes, consolidating the capacities of the Embrapa DUs of the Northern region and partner institutions. The main selection goal is to breed high-yielding cultivars resistant to witches' broom (*Moniliophthora perniciosa*) in basically three steps. The first was initiated in 1984 with collections in Pará and Amazonas to found an Active Germplasm Bank, followed by characterization and evaluation. The second stage of the program was focused on the use of genetic variability made available by clonal selection. Altogether nine clones were selected, four (Belém, Codajás, Coari, and Manacapuru) by Embrapa Eastern Amazon in Pará (Alves and Cruz 2003) and five (BRS 227, BRS 228, BRS 229, BRS 311, and BRS 312) by Embrapa Western Amazon, in Amazonas (Souza et al. 2008). In the third step, the selected genotypes were used in crosses to obtain clones and improved populations. Embrapa Eastern Amazon developed the cultivar BRS Carimbó, released in 2012, derived from the cultivars Coari, Codajás, Manacapuru, and Belém, crossed with each other and with other resistant or more productive genotypes. The progenies were evaluated for 15 years and in the end, 13 mother plants were selected and cloned. The 13 clones and three other genotypes (Coari, Manacapuru and 1074) were planted in an arrangement of isolated blocks. BRS Carimbó originated from the seeds of the crosses of these 16 genotypes (Alves and Ferreira 2012).

The gradual renewal of plantations with improved cupuaçu cultivars reduces the risks for agricultural entrepreneurs by minimizing the threat of an epidemic disease in the orchards and strengthening the production chain that generates direct and indirect employment. In Pará, the main cupuaçu-producing state, there was a resumption of the crop, with an estimated average increase of 30 to 40% fruit yield compared to the regional average and, due to the resistance to witches' broom, with a production cost reduction of 10-20%, by reducing the need for phytosanitary pruning (Alves and Ferreira 2012).

Rubber tree (*Hevea brasiliensis* (Willd. ex Adr. De Juss.) Muell. Arg.)

The regional importance of rubber can be understood by the historical influence of rubber on the Amazonian civilization, when a period was even characterized as "ciclo da borracha", i.e., rubber boom. Explored by extractivism and also cultivated for centuries in the Brazilian Amazon, commercial expansion is restricted by the incidence of the fungus *Microcyclus ulei,* cause of South American Leaf

Blight (SALB), except in some areas of Mato Grosso and Pará, with a longer dry season with leaf fall (Moraes and Moraes 2008). The Brazilian production in 2010 was estimated at 221,829 t by the IBGE (http://www.sidra.ibge.gov.br/), with an estimated value of over U$ 1.1 billion.

The results of breeding for productive and resistant genotypes for replacement of susceptible canopies by cultivars with resistant canopies, tested since 1942 in Fordlandia, and with various hybrids with grafted canopies of *H. brasiliensis* x *H. benthamiana* in plantations in southern Bahia, were rather discouraging, due to the constant resistance breakage by the great variability and mutability of *M. ulei*, the low graft fixation rate at the time, and a lower dry rubber yield (Sousa and Moraes 2001).

Embrapa Western Amazon started a rubber breeding program for canopies with stable *M. ulei* resistance, well-suited for graft fixation. New species were chosen for hybridization with *H. pauciflora* and selection of hybrids with *H. guianensis* var. *marginata* and *H. rigidifolia*, with the same level of stable SALB resistance and good graft fixation (Sousa and Moraes 2001).

The genotypes with the best results for dry rubber yield were CPAA C 01 and C 13 from the crosses *H. guianensis* var. *marginata* (Hgm 1) x *H. pauciflora* (CNS G 112), CPAA C 06 of *H. pauciflora* (CNS AM 7745) x *H. rigidifolia*, CPAA C 16 of *H. pauciflora* (CNS G112) x *H. guianensis* var. *marginata* (Hgm 1) and CPAA C 45 of *H. guianensis* var. *marginata* (Hgm 16) x *H. pauciflora* Baldwin (CBA 1). CPAA C 01 had a higher yield, and is being recommended for the next breeding phase of SALB-resistant rubber cultivars adapted to the conditions of the humid tropical Amazon (Moraes and Moraes 2008).

Inpa

The National Institute for Amazonian Research (Inpa) was created in 1952 and is linked to the Ministry of Science and Technology. The Inpa Vegetable Breeding Program was created in 1975, with the mission of generating knowledge and products for small farmers in the humid tropics to stimulate a diversified production of foods with high nutritional value and easily accessible for the regional population. The strategy to achieve these objectives was selection work on two fronts, based on the levels of genetic adaptability of vegetable crops to hot and humid environments: Conventional Species – well-known and consumed, but with low yields when grown in humid tropical environments; Unconventional Species - with high nutritional value, genetically adapted to cultivation in the Amazon environment, but little known and consumed by urban populations.

In the breeding programs of native fruit trees, two species are particularly promising: peach palm for heart-of-palm production, aiming to increase the length of the palm heart for high yield per stem and camu-camu fruit production, aiming to increase the ascorbic acid content.

Tomato (*Lycopersicon esculentum* Mill)

The best-known and most-consumed conventional species in the Amazon region are the same as in other Brazilian regions, for example the vegetables. The tomato breeding program of Inpa began in 1976. Research was directed primarily towards the incorporation of genetic resistance against the pathogen *Ralstonia solanacearum* (Smith), causal agent of the bacterial wilt disease, a limiting factor for cultivation in the humid tropics. The bacterium *R. solanacearum* was considered a component of soil biodiversity and on this basis, the genetic pathogen resistance of the host is expected to remain stable over time, in the different cultivation environments versus the extreme genetic variability of the pathogen, and to the environmental stresses that can negatively affect the resistance expression. Thus, methods were adopted that allow reliable assessments of the resistance level of the selected progenies, taking into account all factors involved in the complex host - pathogen - environment interaction.

The genealogical selection method, based on a cross called HT-16, gave rise to variety Yoshimatsu (Noda 2007), with high polygenic resistance to the pathogen, confirmed in tests carried out in Brazil and abroad (Prior et al. 1996, Oliveira et al. 1998). The adaptation to and phenotypic stability in lowland areas (floodplains) and dryland infested with the pathogen were confirmed for advanced lines of Yoshimatsu (Pena et al. 2010).

Cultivar Yoshimatsu is an important research contribution to the regional horticulture for enabling the cultivation of tomato in the Amazonas and Amapá. The conventional cultivars adapted to the Amazon basin are important, not only for reducing production costs for seed purchase, but also to facilitate the access of consumers with lower purchasing power and to contribute to food security in rural communities, where most of the production is for household consumption.

Cocona (*Solanum sessiliflorum* Dun.)

Cocona is native to the western Amazon region, a species domesticated by the Indians of the region. The socioeconomic potential of this Solanaceae for Amazonian farmers is great, for being high-yielding, producing up to 100 t ha^{-1} fruit, depending on the genotype. The fruit has a characteristic taste, particularly the placenta pulp (tissue forming the locular cavity holding the seeds), which is slightly acidic and much more tasty than the pulp adhered to the shell. The main use is for fruit juices, jams, jellies, stewed fruit, or sauce (hot or sweet) to accompany any kind of barbecue meat. The Peruvian Indians and Caboclos use pure cocona juice to make their hair shiny. Recognizing the properties of cocona, some products were developed, e.g., soaps, face creams, shampoos, and perfumes (Silva Filho et al. 2005).

The Inpa germplasm collection in Manaus contains 162 subsamples of cocona populations that are being exploited in breeding. In the process of cultivar selection, the subsamples were characterized and evaluated for the traits: adaptability, fruit shape, size, and number, yield, and response to pests and diseases under field conditions. The result was the selection of 28 lines for comparison tests, in which one line was selected that gave rise to cultivar Luyama. The fruits of Luyama are berries, with a weight of 80 g and estimated fruit yield of 80 t ha^{-1} (Silva Filho 2009).

Until 2000, cocona was a little-known vegetable, grown only in counties of the Upper Solimões region. Currently, it is produced by family farmers living in rural areas of the metropolitan area of Manaus, generating income and employment in horticulture in the state of Amazonas. In other Brazilian regions, such as the Southeast, mainly in São Paulo, the introduction and cultivation began about five years ago.

Camu-camu (*Myrciaria dubia* (Kunth) McVaugh)

The camu-camu fruit, rich in vitamin C, is a species native to the Amazon, growing in natural or wild state along most rivers, lakes and in flooded forests of the Amazon basin. It is tolerant to flooding and can remain under water for 4 to 5 months (Yuyama 2011a). In the 1980s, samples were collected to found an Active camu-camu Germplasm Bank, with currently 160 accessions. The camu-camu breeding program is based on the agronomic traits described by Yuyama (2011b), of an ideotype plant, which has the primary function of finding genotypes that maximize yield, with special emphasis on higher contents of ascorbic acid. Another goal is the uniformity of fruit ripening in the field and more harvests per year in dryland areas, by massal selection of plants in experiments with different fertilizer forms and sources. Camu-camu adapts well to nutrient-poor as well as to nutrient-rich soils (Yuyama 2011b).

There is genetic variability in the type of leaves, plant architecture, fruit size, and ascorbic acid content. Great variation among accessions has been observed, indicating that further studies of ethnobotany, biology (physiology, reproduction/propagation, etc.) of this species are needed, as shown by Gonzalez et al. (2011) with molecular markers and by Espirito Santo and Yuyama (2011) in a study of functional genomics. Moreover, the information from the evaluation of agronomic, chemical-nutritional and other traits is essential to use camu germplasm. In the evaluations, genotypes with an ascorbic acid content of over 3200 mg 100 g^{-1} pulp were selected, e.g., UAT14.96.2, UAT04.96.2, CAU.01.97.9, and UAT11.96.7 (Yuyama 2011b).

Peach palm (*Bactris gasipaes* Kunth.)

Domestic production of palm heart rose from 24,356 to 116,495 t in the first decade of the 21st century (IBGE, http://seriesestatisticas.ibge.gov.br). Market growth and the low sustainability of the forest extraction of palm heart contributed greatly to the expansion of peach palm plantations in the country, causing a positive impact on research on peach palm breeding for palm heart.

For the agribusiness, peach palm has the great advantage of early extraction of the palm heart, in the very first year after planting (Yuyama et al. 2002). Inpa started a peach palm breeding program in 1991 to select thornless genotypes and raise the profitability of palm heart production based on the traits earliness, number of tillers, and palm heart length and quality. The result was the selection of plants with palm length of over 45 cm within and between progenies of four provenances from the region of Yurimaguas, Peru (Cuiparillo, Huallaga (main channel), Paranapura and Shanusi Rivers) (Yuyama et al. 2002).

Ceplac

The Executive Planning Commission of Cocoa Farming - Ceplac, a body linked to the MAPA, was created in 1957, to upheave cocoa cultivation in southern Bahia. In 1965, faced with the need to broaden the genetic variability of the species, a basis was established in Belém, Pará, for the reception of the plant material collected in the Brazilian Amazon and subsequent transfer to Bahia. This basis was also equipped to develop studies on the adaptability of cocoa to the ecological conditions in the Amazon. Currently, Ceplac is engaged in research in six Brazilian states: Bahia, Espírito Santo, Pará, Rondônia, Mato Grosso and Amazonas.

Cacao (*Theobroma cacao* L.)

The fermented and dried cocoa beans are used for extraction of cocoa butter, powder, liquor, cakes and especially for chocolate manufacturing. Currently, the Brazilian cocoa production is insufficient to meet the demand of the domestic market, which rose from a per capita consumption of 400 g in 2003 to about 1,300 g. There is also an increased demand for chocolates with high cocoa content and growing foreign markets that will require an increase in the world cocoa production of about 650 t in the next five years (CEPLAC 2012. Cocoa farming is a relevant part of economy in 223 cities in 6 states in Brazil, involving about 60 thousand rural producers. In the harvest of the 2011/2012 growing season, the Brazilian production reached 245,400 t, requiring the importation of at least 80,400 t of dried cocoa beans. About 32.3% of this amount is produced in Amazonas, on around 124,600 ha (IBGE 2012).

The confirmation of the hybrid vigor in cocoa in the 1950s (Montserin et al. 1957) and the ease of maintaining clonal parents for hybrid seed production stimulated an intensive use of hybridization in the following decades, resulting in improved varieties for the major cocoa-producing regions. The same is true for the Brazilian Amazon where, however, the traits resistance to witches' broom *Moniliophthora perniciosa*, endemic to the region, and increased yield and earliness are breeding objectives as well. In the beginning, crosses between parents known in other countries and selections found on botanical expeditions to the Brazilian Amazon were preferred, to broaden the genetic basis of resistance to *M. perniciosa,* underlying the search for horizontal resistance in improved varieties. Parents from the "common" population of southern Bahia were also used. Over 350 interclonal crosses were evaluated, especially for the ecological conditions of Pará and Rondônia. This test program was the technical-scientific basis for the identification of the hybrid variety currently recommended for the Amazon. In the last years, the breeding objectives were shorter plant height and more productive, early and pest-tolerant clonal varieties, aside from the trait seed quality for distribution to farmers.

The cultivars distributed to cocoa farmers in the Brazilian Amazon are hybrid varieties generally consisting of a blend of 10-20 interclonal crosses with higher yield, earliness and pest tolerance. The purpose of this mixture is primarily to reduce the risk of pest spreading in the plantations, particularly of witches' broom, by the genetic heterogeneity of its components, and to provide a balanced equilibrium of cross-pollination for new plantations, using self-incompatible parents in the production of improved seed. If the recommended management technology is adopted for cacao in the Amazon, yields above 1200 kg ha^{-1} yr^{-1} of dried cocoa beans in upland areas are expected from the eighth year of field cultivation. This productivity level is over four times higher than that of unimproved plantations.

In economic terms, the expansion of cocoa plantations in the Brazilian Amazon has led to the formation of two well-established cacao centers: Pará and Rondônia, which together represent a total cultivation area of about 124,600 ha. This agricultural heritage produces over 74,000 t of dry cocoa annually (98.8% of the total Amazonian cocoa production) and generates annual gross revenues exceeding U$ 310 million. From the social point of view, this shows the importance of the crop for labor retention in rural areas, especially of subsistence farmers in agrarian reform areas. In this universe, the number of producers who have better living conditions and access to durable goods and commodities they never had before is now approaching 26 thousand. Around 49,000 direct jobs in the country are generated on a permanent basis and 196,000 indirect employments. From the environmental viewpoint, the cultivation of cacao in agroforestry systems has the sustainability features of a mixed forest in terms of soil protection against degradation agents, rational use of space and light, nutrient recycling and use of the residual effect of exogenous fertilization, among others (Alvim 1989). In view of its preservationist nature, cacao cultivation constitutes an alternative to meet environmental liabilities.

TRAINING OF HUMAN RESOURCES IN BREEDING IN THE NORTHERN REGION

Federal University of Amazonas - UFAM

The Doctoral Course in Tropical Agriculture (PPG-AT) of the UFAM was approved in 2006, in partial association with Embrapa Western Amazon. The course is based on agriculture with a focus on preservation and valorization of the rainforest and the Amazonian peoples who live there. The course Genetics and Breeding was created as research line within the framework of the program to prepare professionals to work in the reality of the Amazon region. To strengthen the efforts towards the research objectives, agreements were signed with Inpa and Embrapa and many projects are developed among PG-ATR researchers along the line of research of these institutions. A project with the Universidade Federal de Viçosa was also developed: "Academic Cooperation UFAM / UFV for the development of studies on genetics, breeding and plant structures in the Amazon region" (PROCAD of CAPES/2006).

The inter-institutional partnerships have significantly contributed to the consolidation of research in Genetics and Breeding, through the improvement of infrastructure, participation of teachers of the partner institutions, in lecturing courses and in examination advisory committees, as well as in the growing exchange of faculty, generating the synergy required for the advancement of research and the PG-ATR. The UFAM also offers a doctoral course in Biotechnology, with areas related to plant breeding and training with tools such as molecular markers and recombinant DNA technology.

Therefore, the main contribution of the Federal University of Amazonas to the regional breeding programs is to consolidate this line of research, providing training and retention of a greater number of breeders in the North.

Federal Rural University of Para - UFRPA

The UFRPA was officially founded in 2002 and is specialized in Agricultural Sciences, offering eight graduate and seven postgraduate courses on the Campus in Belém. One discipline of the agronomy graduate course is "Plant Breeding Methods" and "Forest Improvement" for forestry engineering. At the Master's level in Forest Science and the Doctoral level in Agricultural Sciences (in partnership with Embrapa Eastern Amazon), the disciplines "Plant Genetic Resources" and "Agrobiodiversity in the Amazon" are offered.

In the development of research programs in the area of Genetic Resources and Agrobiodiversity, the main focus are participatory breeding and the native species used by farmers in northeastern Pará.

In the area of forestry, the breeding program teamed up with the private sector, with a special focus on improving the native Brazilian tree species firetree (paricá - *Schizolobium parahyba* var *amazonicum* (Huber ex Ducke) Barneby) to breed genotypes with improved growth and wood quality. To this end, promising plant material was selected from reforestation areas in Pará, with support of the forestry group Rio Concrem Industrial. The selected genotypes are being vegetatively propagated and seed production areas established for recombination and for genetic gains in better yield and wood quality. In the partnership project Forest Biomass Network, the UFRA/Embrapa Eastern Amazon/ Rio Concrem, are working together to obtain high-quality genotypes of the Brazilian firetree by exploiting the genetic variability.

The production of improved seeds and the development of genotypes for intra and interspecific hybridization and the use of clonal propagation have made an enormous difference in the economic performance of forestry. The results contributed significantly to the main qualitative and quantitative gains achieved in the last decades of the 20th and in the beginning of the 21st century. For the exotic species native to the Amazon region, however, studies are scarce.

CHALLENGES AND PROSPECTS

An important aspect of oil palm cultivation is the current rapid expansion promoted by government programs and the market entry of large companies mainly interested in oil production for biofuel, with increased demand for seeds. So one of the challenges is to begin a new breeding cycle of tenera cultivars, using methods that shorten the selection cycles and accelerate genetic gains. Another challenge is to develop cultivars of FY-resistant interspecific hybrids that do not require assisted pollination, a practice that raises production costs. To this end, backcrosses with African species as recurrent parent are being tested. The expectation is to find high-yielding, fertile and FY resistant backcrossed genotypes that can be cloned for cultivation in the area of FY-incidence, without requiring assisted pollination. This will reduce production costs and increase the producers' profit.

The acai palm improvement program is using intra- and interpopulation recurrent selection of the two species *E. oleracea* and *E. precatoria* for fruit production and especially for interspecific hybrids combining the desirable traits in partially or fully fertile hybrids. This strategy will also allow the selection of trees with advantageous traits for heart-of-palm production, landscaping and logging.

The determination of the guarana species involved in the event of ploidy that are part of the primary gene pool is a challenge for the future of the breeding program. It is expected to broaden the genetic basis of the crop to ensure further gains from varieties with wide adaptability, good stability and resistance to anthracnose and oversprouting. The selection of plants with superior traits should increase the production level to a minimum of 1.5 kg $plant^{-1}$ yr^{-1} of dry seeds.

The greatest challenge of improving cacao and cupuaçu is to achieve durable resistance to the witches' broom fungus *Moniliophthora (Crinipellis) perniciosa*, which has a history of co-evolution with the crops in the Northern region. Therefore, the programs of the two crops should continue in the search for an expansion of the genetic basis of resistance to *M. perniciosa*, considering the high variability and adaptability of this pathogen. Another challenge is that the cocoa disease moniliasis (*Moniliophthora roreri*), common in neighboring countries and also a threat to cupuaçu, could reach the plantations in the Brazilian Amazon. For these crops, it is expected that resistance genes could gradually be incorporated into seed or clonal cultivars for recommendation in recurrent selection cycles, without reducing the genetic variability of the population.

A sustainable vegetable production in the Amazon region depends on finding appropriate strategies and technologies that can adapt the species to the main environmental stresses of the humid tropics. The cation exchange capacity in soils of upland ecosystems is mostly low and an inadequate management of this natural resource could compromise the sustainability of annual crop species. The natural soil fertility in the floodplain ecosystem of the nutrient-rich white-water rivers is high, but represents a small portion of the Amazon territory, which tends to be used only during the short non-flooded period.

Genetic studies can be a support of breeding programs, but a close cooperation is imperative, in view of the functional potential of camu-camu, opening far-reaching possibilities of future studies, specifically related to the biosynthesis, degradation and recycling of ascorbic acid.

The peach palm breeding program was restructured in a national research project coordinated by Embrapa Forest, a DU based in Paraná, with participation of Inpa, Embrapa and partners. The challenge is to improve the heart-of-palm production in various regions of the country, including the North, with the breeding strategy of intrapopulation recurrent selection based on successive evaluation cycles of open-pollinated progenies.

The characterization and evaluation of the available germplasm and the integration of biotechnology to traditional methods are important supports for successful breeding programs, especially native species, the main focus of the programs of the institutions in the Northern region. However, the progress in the programs depends on investment in infrastructure, in human and financial resources, to ensure continuity and efficiency in meeting the demands of agriculture with economic, social and environmental gains.

FINAL CONSIDERATIONS

The results achieved are not more extensive because of the small number of researchers working in the field of breeding in the Northern region and the faint-hearted investment in the program. This is partly because the agricultural activity in the region is less significant than in other regions of the country, requiring the provision of resources beyond the demand for the development of studies and new genotypes. It is worth mentioning that the domestication and breeding of native species is a way to exploit the Amazonian biodiversity for the general benefit of society and represents a major national challenge. Therefore, policies to foster research institutions in the Northern region should be a subject of deliberation and action of the scientific and technological community in Brazil.

Contribuição das Instituições da região Norte no desenvolvimento de cultivares de plantas e seu impacto na agricultura

Resumo - *O artigo apresenta a evolução dos programas de melhoramento genético desenvolvidos na região Norte do Brasil e seus principais impactos na agricultura. Destaca as contribuições do melhoramento das espécies palma de óleo, açaí, cacau, cupuaçu, guaraná, tomate, camu-camu, cubiu, pupunha e seringueira. Os avanços nos programas das instituições que estão envolvidas com melhoramento, como a Embrapa, Ceplac, Inpa e as Universidades, estão condicionados ao investimento na infraestrutura, em recursos humanos e financeiros para que possam ter continuidade e serem eficientes em obter ganhos econômicos, sociais e ambientais. O melhoramento das espécies nativas, foco principal dos programas das instituições na região Norte, é uma forma de uso da biodiversidade em benefício da sociedade. Portanto, as políticas para o fortalecimento das instituições de pesquisas devem constituir tema de reflexão e ação da comunidade científica e tecnológica brasileira.*

Palavras-chave: *Melhoramento de plantas, Amazônia, espécies nativas.*

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