Chemistry of Tropical Root Crops:

Significance for Nutrition and Agriculture in the Pacific

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Chemistry of Tropical Root Crops:
Significance for Nutrition and Agriculture in the Pacific

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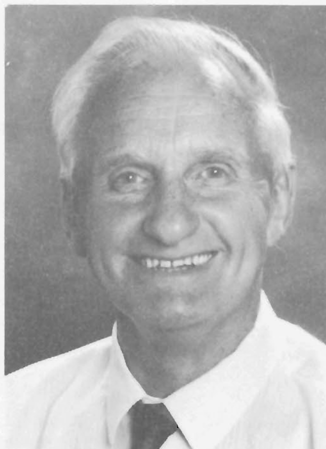

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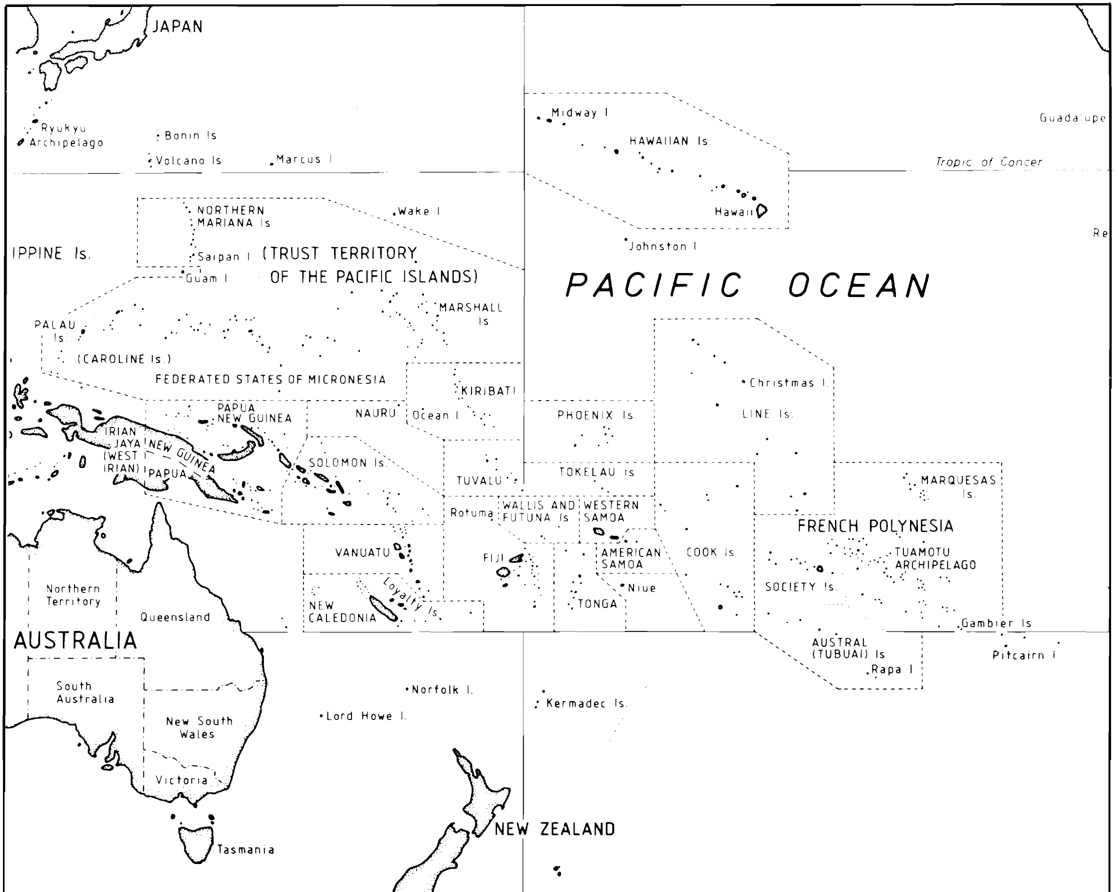
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Bonin Is
Volcano Is
Marcus I
Midway I
HAWAIIAN Is.
Hawaii
Guadalupe
Tropic of Cancer
NORTHERN MARIANA Is
Wake I
Saipan I
(TRUST TERRITORY OF THE PACIFIC ISLANDS)
Guam I
IPPINE Is.
Johnston I
PACIFIC OCEAN
PALAU Is.
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MARSHALL Is
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Foreword

Root crops are a staple food in many countries throughout the tropical regions of the world. Varieties may differ greatly in their nutritional value, and it is important for alleviation of malnutrition that the best varieties be chosen. However, nutritionists and agriculturalists have frequently not had access to relevant analytical data. This is particularly so in the Pacific Islands where several species important in atoll countries are not widely grown elsewhere. Root crops such as sweet potato, cassava, yams and several types of taro are staple foods throughout the region.

In 1983 ACIAR commenced a project to determine the chemical composition and nutritional status of a wide range of Pacific root crops. Over the past four years, Dr Howard Bradbury and a number of colleagues at the Australian National University worked with 17 collaborators in eight Pacific countries to provide a wealth of chemical information about Pacific root crops. This book is a compilation of the data resulting from their study.

The results obtained compare well with more fragmentary data published elsewhere. The present information is not country-specific, and should be of value to nutritionists and agriculturalists concerned with tropical root crops worldwide. The volume contains a literature review summarising previously published data as well as the original data generated in the ACIAR project.

The publication is thus a comprehensive text on the chemistry of tropical root crops.

The contribution to this work of scientists and nutritionists in several Pacific countries, and from the South Pacific Commission, is gratefully acknowledged. The project was one of the first supported in ACIAR's South Pacific program, and we are pleased to see it coming to fruition.

Canberra
11 April 1988

Gabrielle J. Persley
Research Program Coordinator
Crop Sciences
ACIAR

Preface

We live in a crazy world. On the one hand we read of a surplus of wheat and mountains of butter and meat, and on the other we see on our TV screens the spectre of starving people. We can attempt to rationalise this by pointing to the unequal distribution of food and wealth between the developed (rich) and the developing (poor) countries, and the further inequalities of wealth between individuals within any particular developing country. This disparity between developed and developing countries should be reduced. Unfortunately the level of aid from some of the richer nations has progressively declined in real terms over the last few years. An increased awareness and concern by the people of the developed world towards the poor and hungry in developing countries is needed.

The prevalence of protein energy malnutrition amongst children under 5 years old has been compared worldwide using weight for age data for the periods 1963–73 and 1973–83. It is impossible from the results to determine if malnutrition is getting better or worse, but the total number of malnourished children increased by 15% in the second period to 145 million (Weekly Epidemiological Record 1984). The numbers are so large that they tend to lose significance. The 166 Member States of the World Health Organization have recently adopted a universal goal of health for all by the year 2000 (WHO 1986a). Global indicators for monitoring progress towards health for all have been developed including, for example, an estimated probability of a child dying before the age of 5 years. This indicator varies from 1.2% in Australia and the United Kingdom to greater than 30% in several African countries (WHO 1986b).

The increase in the population of the world can be described by noting that it took 130 years after 1800 to add a second billion, 30 years after 1930 to add a third billion and 15 years to add a fourth billion. The rate of increase of population peaked in the early 1960s. The population in 1984 was 4.8 billion, an increase of 81 million in one year. Most demographers project that world population will eventually stabilise at around 10 billion people (Brown et al. 1985). Today about 75% of the world's people live in developing countries and about 90% of the increase in population will take place in present-day developing countries. Thus, virtually all the additional pressure on global resources of food will occur in those areas of the world least able to withstand it. Most of the developing countries fall within the tropics and therefore the need for additional food resources will be most acutely felt there.

It is, therefore, particularly important to carry out research on tropical food crops. There are two major reasons why tropical root crops should be chosen for study. First, they are staple foods of hundreds of millions of people, particularly poor people, in Latin America, Africa and Asia. Improvements in yield or in the nutrient content of tropical root crops would therefore benefit the poorest people, those who do not have the money to purchase cereals such as rice or maize (Norman et al. 1984). Second, compared with the large amount of research carried out on crops that are important in developed countries, research on tropical root crops is small (Coursey 1983a). In recent years research has been carried out on sweet potato at the Asian Vegetable Research and Development Center (AVRDC) in Taiwan and

the Centro Internacional de la Papa (CIP) in Peru, on cassava at the Centro Internacional de Agricultura Tropical (CIAT) in Colombia and on cassava, yams and sweet potato at the International Institute of Tropical Agriculture (IITA) in Nigeria. However, having regard to the worldwide importance of these root crops in subsistence agriculture (see Chapter 1), there can be no question that the current level of research is inadequate.

The situation in the South Pacific is different from that in other countries where tropical root crops are grown. In the South Pacific, tropical root crops are the major staple foods of the indigenous people and as such are a prime object of research. Furthermore, much of the research of the international centres (AVRDC, CIP, CIAT and IITA) is not applicable to the agricultural subsistence systems of the South Pacific. Thus, root crop species differ, pests and diseases differ and the edible aroids (taro) are much more important and cassava less important than elsewhere. The small amount of research worldwide on the edible aroids is being done in research centres around the Pacific and South Asia.

In the South Pacific, selection and breeding programs are in progress in Solomon Islands for taro and sweet potato, in Fiji for taro, in Western Samoa for taro, in Tonga for sweet potato, in Papua New Guinea for sweet potato and in Vanuatu for yams. Over the past four years, workers in these countries and also in Kiribati and Pohnpei State (Federated States of Micronesia) have sent samples of their popular and elite cultivars to the ACIAR/ANU Program on Nutrition of Tropical Root Crops in the South Pacific at Canberra, Australia, where they have been analysed for all major nutrients.

The major aim of the Program has been to obtain a comprehensive set of nutrient data on the root crops, which may be used by nutritionists in the region. Currently there are considerable gaps in the nutrient data for tropical root crops, but the general consistency of much of the data obtained worldwide with our data (see Chapter 3) confirms that our comprehensive data set may be used throughout the world. Furthermore, it is important to nutritionists, plant breeders and other specialists in the South Pacific countries to have data available on the particular cultivars that are popular in their own country. These data are given in the Appendix tables. Other aims of the program included a study of the effect of cooking on nutrient content of the major root crops (Chapter 4), a study of antinutritional factors such as acridity in the edible aroids, cyanide in cassava and trypsin inhibitors in all root crops (Chapter 5) and studies of the effects of various environmental factors during growth on yield and nutrient content (Chapter 6).

This project has been supported financially and in other ways by the Australian Centre for International Agricultural Research (ACIAR). In order to make the data available to a wide audience in the South Pacific and to nutritionists and tropical root crop specialists throughout the world, it was decided that a monograph should be published by ACIAR. This is the result.

The work has represented a team effort which has involved seventeen collaborators from nine countries of the South Pacific whose names and addresses are given following the title page. Also involved were nine co-workers from the Chemistry Department at ANU who carried out nearly all the analyses. To these people we tender our grateful thanks. Thanks are also due to Dr Grahame V. H. Jackson who was involved in the development of the original program, and has made constructive suggestions throughout its course, Dr Gabrielle J. Persley of ACIAR who facilitated and supported the program, and the Director of ACIAR, Dr J. R. McWilliam, for financial support, without which this project would not have been possible.

In the production of this book there are many persons who have read and made comments on either the whole manuscript or parts of it. These include M. Alpers,

R. M. Bourke, R. L. Hide, G. V. H. Jackson, P. R. Linton, S. Parkinson, M. F. Quin and J. E. Wilson. Messrs P. Ferrar and R. MacIntyre of ACIAR are thanked for their facilitation of the project and work on publication of the book respectively. We wish to thank our typist Mrs Inta L. Payne for her sterling efforts in the production of the manuscript. Finally one of us (JHB) wishes to thank his wife for her forbearance and understanding during the long and intense period of writing this book.

J. Howard Bradbury
Warren D. Holloway

Chapter 1. Introduction

The major tropical root crops of the world are cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), yams (*Dioscorea* spp.) and taro (*Colocasia esculenta* and *Xanthosoma sagittifolium*). The world production of these crops in 1985 was 136, 111, 26 and 5.6 million t, respectively. In terms of world production, these tropical root crops are fifth behind wheat (510 million t), maize (490 million t), rice (466 million t) and white potatoes (299 million t) (FAO Production Yearbook 1985). The total world production of all root crops exceeds that of wheat.

In the South Pacific, taro is relatively much more important and cassava much less important than elsewhere in the world. Taro (*Colocasia esculenta* var. *esculenta* and *C. esculenta* var. *antiquorum,* and *Xanthosoma*) are the most important members of the edible aroids which form part of the Araceae family. The other three members are of minor importance worldwide, but are of some importance in the South Pacific, viz. giant taro (*Alocasia macrorrhiza* var. *macrorrhiza*), giant swamp taro (*Cyrtosperma chamissonis*) and elephant foot yam (*Amorphophallus campanulatus*) (Onwueme 1978; Plucknett 1983; Sakai 1983).

The large number of common names used for some of the root crops is indeed confusing. For example, taro (*C. esculenta* var. *esculenta*) is called taro in the Pacific and Asia, dasheen in the West Indies and old cocoyam in Africa; taro (*C. esculenta* var. *antiquorum*) is called eddoe in the West Indies and dasheen in the Pacific and Asia, and *Xanthosoma* is called tannia or new cocoyam in Africa (Onwueme 1978; Plucknett 1983).

1.1 Agriculture

Tropical root crops are grown widely throughout the tropical and subtropical world and are the staple food for 400–500 million people. They are grown over a range of climates and altitudes and on a variety of soils. Cassava and sweet potato are grown from high rainfall to semi-arid regions because they tolerate drought and will grow in a wide range of soils. Taro, however, is best adapted to wet and flooded areas and is also tolerant to shade. They are grown largely for home consumption in gardens and smallholdings and rarely appear on world markets, except when grown for industrial use (e.g. cassava for starch production, and cassava and sweet potato as livestock feed). The edible green leaves of sweet potato, taro and cassava are a good source of protein, vitamins and minerals and are often used to augment the diet.

Some root crops, like sweet potato and cassava, require little attention after planting. This is why the energetic efficiency of nonmechanised crop production (i.e. the average energy ratio of output by the crop/input by the farmer for rainfed cereals or sweet potato, cassava or yams) is higher for tropical root crops at 42–60:1 than the cereals 9–39:1 (Chandra 1981; Norman et al. 1984). Cassava and the edible aroids may

be left in the ground until they are needed for eating (Cobley and Steele 1976; Hahn 1984). Root crops therefore form a valuable, sustained food supply when other crops fail, and are much less subject to damage by cyclones than tree crops or cereals.

The high efficiency of tropical root crops as food producers is due partly to their plant architecture, because strength in the plant stem is not needed to support heavy tubers and corms (Hahn 1984). This efficiency may be compared in terms of yields. For cassava and sweet potatoes the average yield worldwide in 1985 was 9.6 and 13.9 t/ha respectively, and for rice paddy was 3.2 t/ha (FAO Production Yearbook 1985). A better measure of efficiency may be calculated in terms of the comparative edible energy yields of the crop per hectare per day. The edible energy yields for rice, cassava and sweet potato are calculated as 149, 138 and 194 MJ/ha/day, respectively, which shows that sweet potato is probably more efficient in energy production than cassava and rice (table 4.2 of Norman et al. 1984). This agrees with the results of calculations in Japan where the sweet potato has an average yield of 21 t/ha from which the edible energy is 1.23×10^5 MJ/ha, which is 1.9 times that of rice with an average yield of 4.5 t/ha (Hahn and Hozyo 1980); the average crop growth period is about the same for the two crops. In a similar way, it is possible to calculate the average protein yield from tropical root crops, cereals and legume crops. It is found that the average protein yield of cassava, sweet potato and yams (100–140 kg/ha) is about the same as that of rice, maize, beans and chickpea and less than that of groundnut (217 kg/ha) and soybean (505 kg/ha) (tables 4.3 and 14.2 of Norman et al. 1984). A disadvantage of root crops is that, except for yams, they cannot be stored for long after harvest, and because they perish rapidly (see section 4.6), they are difficult to transport to markets. A more detailed consideration of the various root crops follows.

1.1.1 Sweet potato, *I. batatas*

Sweet potato is a creeping plant (Fig. 1.1 and 1.2) and the only economically important species of the family Convolvulaceae (Cobley and Steele 1976). The starchy, tuberous roots are the major source of food, but the leaves are also a useful source of vegetable greens in some countries (Villareal et al. 1979, 1982; Pace et al. 1985a, b). The plant originated in tropical America and from there has been taken throughout the world (Yen 1982). Sweet potato is ranked seventh in world production after wheat, maize, rice, potato, barley and cassava (FAO Production Yearbook 1985). The largest amount (81%) is grown in China which, combined with other Asian countries, accounts for more than 90% of production. In Papua New Guinea (PNG) it is the major crop and the staple food (Bourke 1982, 1985a). It is also the staple food in parts of the Philippines (Villareal 1982), Solomon Islands, and Tonga.

Sweet potato is grown in a very wide range of environments, in the tropics from sea level to altitudes of about 2700 m (Bourke 1985a), and in temperate climates, in the absence of frost, in China, Japan, USA, New Zealand and Australia. It is a perennial plant but is normally grown as an annual. It is propagated from vine cuttings in the tropics and from tubers in temperate zones. Flowering occurs readily in the tropics where day lengths do not exceed 13.5 hours, but is rare in temperate latitudes. The crop is self-incompatible, out-breeding and the production of seeds combined with the normal vegetative propagation favours the accumulation of a large number of cultivars (Cobley and Steele 1976). Sweet potato accessions number 1200 for PNG and a total of 1660 for an incomplete listing of South Pacific countries (Jackson and Breen 1985). Accessions represent different cultivars which have not been exhaustively compared to see whether duplicates exist in the collection. Bourke (1985a) estimates that there may be 5000 cultivars in PNG. A major problem in the lowland tropics is infestation of the tuber with sweet potato weevil (*Cylas formicarius*), related species *C. puncticollis* (Talekar 1982) and *Euscepes postfasciatus*. In Tonga, *E. postfasciatus* is

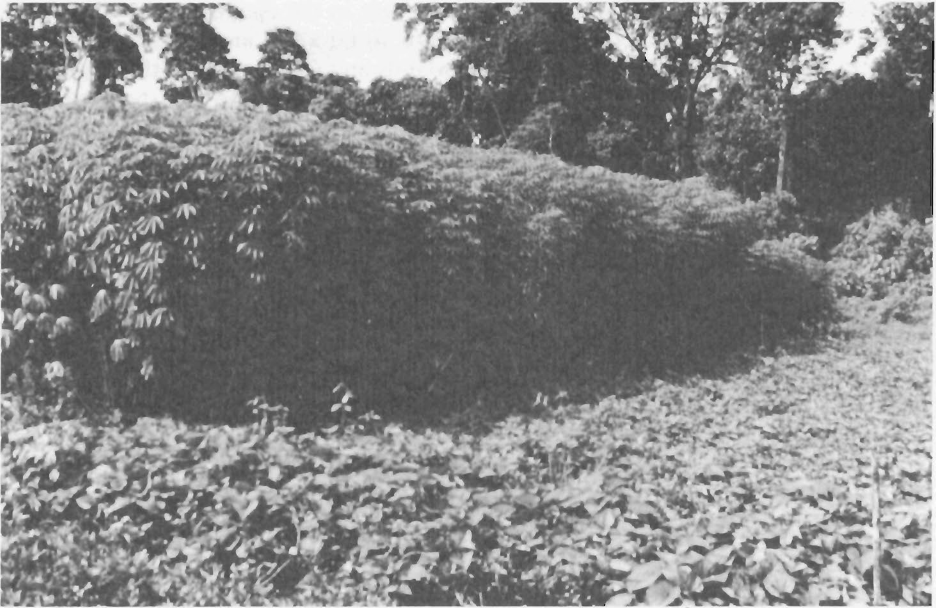


Fig. 1.1 Sweet potato in the foreground with cassava behind at Dodo Creek Research Station, Tenaru, Solomon Islands.

Fig. 1.2 Freshly dug sweet potato tuber and plant, Visayas State College of Agriculture, Leyte, Philippines.

considered to be the most important root crop pest in the country (Van Wijmeersch 1986). In PNG yields vary from crop failure to 70 t/ha but are usually 10–40 t/ha. Time to maturity is 4.5–6 months in the Lowlands and 6–8 months in the Highlands, and the tubers are usually progressively harvested as they develop and the need arises (Bourke 1985a). Sweet potatoes with white to cream-coloured flesh are usual in the South Pacific, whereas American sweet potatoes normally have yellow to orange flesh, and there are differences in chemical composition between them (see section 3.10).

1.1.2 Taro, *C. esculenta*

Taro *Colocasia* and *Xanthosoma* are the most important edible aroids and are members of the Araceae family (Plucknett 1983; Chandra 1984). Taro *Colocasia* is a very ancient crop that originated from Asia, probably India (Onwueme 1978; Wang 1983; Cable 1984) and was taken to Egypt, where it was called qolqas and was an important food there 2000 years ago (Darby et al. 1977; Parkinson 1984b). It is one of the most widespread of the root crops, being grown to some extent throughout the humid tropics. About 60% of world production of 5.6 million t is grown in Africa and most of the remaining 40% in Asia and the Pacific (FAO Production Yearbook 1985). There are two varietal types of *Colocasia: C. esculenta* var. *esculenta* which produces a large edible corm with a few suckers (cormels), and *C. esculenta* var. *antiquorum* which has a small or medium-sized corm and a large number of small edible cormels (Onwueme 1978; Plucknett 1983). In the Pacific, taro *C. esculenta* var. *esculenta* is of major importance and var. *antiquorum* is only rarely present (Sivan 1981; Bourke 1982), hence all further reference in the book to taro *Colocasia* refers to var. *esculenta* and not var. *antiquorum*.

Taro *Colocasia* (Fig. 1.3 and 1.4) needs fertile soil and a rainfall of at least 2000 mm/annum (Onwueme 1978). It grows in the tropics from sea level up to 2700 m (Bourke 1982) with reduction of yield and increased time to maturity at higher altitudes. It has a low tolerance to frost. Time to maturity is generally 7–9 months at sea level, but it may be as short as 4 months, and up to 18 months at high altitudes (Bourke 1982). Corm yields are variable; in Hawaii 20–30 t/ha/year (Wang 1983), in Fiji 10–30 t/ha (Sivan 1984), and in PNG 4–13 t/ha (Bourke 1982). The average yield worldwide is 5.6 t/ha (FAO Production Yearbook 1985). There is a wide variety of pests (Mitchell and Madison 1983) and diseases (Jackson 1980a; Ooka 1983) of *Colocasia* with perhaps the taro beetle (*Papuana* spp.) and leaf blight, caused by the fungus *Phytophthora colocasiae* being the most serious. There are 722 accessions so far recorded in collections in South Pacific countries, with the largest numbers in PNG and Vanuatu (Jackson and Breen 1985). The leaves and corms of certain cultivars of taro *Colocasia* are acrid (see section 5.4), but leaves and stems of non-acrid varieties are used widely as a green vegetable and in salads and traditional dishes in the Pacific (Standal 1983; Parkinson 1984a, b). Taro *Colocasia* requires high labour inputs for weed control compared with sweet potato. Corms may be progressively harvested as required, but they do not store well (see section 4.6).

For a variety of reasons, taro *Colocasia* is in decline in PNG and Solomon Islands, being largely replaced by sweet potato (Bourke 1982). In Fiji the area planted to the crop has decreased, although production has actually increased as yield per hectare has increased, and cassava production has increased (Sivan 1981, 1983). However, in most South Pacific countries taro *Colocasia* remains a prestigious food and in some countries such as Western Samoa, production has increased because of export demand from Pacific Islanders living in New Zealand and Australia.

Fig. 1.3 Taro (*C. esculenta*) growing in foreground with bananas above in Western Samoa.

Fig. 1.4 Taro (*C. esculenta*) corms at Suva market, Fiji.

1.1.3 Taro, *X. sagittifolium*

This species (Fig.1.5) originated in tropical America and spread to Asia, the Pacific and Africa probably in the 19th century (Onwueme 1978). It requires high rainfall but cannot tolerate continuous flooding. It can withstand drier conditions and lower soil fertility than *Colocasia* but like *Colocasia* is shade tolerant.

The main corm is usually not eaten, presumably because of its acridity, and is used for planting setts and fed to animals (Bourke 1982; Van Wijmeersch 1986). Plants produce many cormels that are eaten and yields are normally higher than *Colocasia*. *Xanthosoma* is less subject to pests and diseases than *Colocasia*. As with *Colocasia*, the stems and leaves are used in salads and as a green vegetable. The cormels store better than the corms of *Colocasia* (see section 4.6). *Xanthosoma* is of much less importance in the South Pacific than *Colocasia* although in Tonga it is second in importance to cassava (Sivan 1981; Bourke 1982; Van Wijmeersch 1986). Only 32 accessions have been documented in the South Pacific (Jackson and Breen 1985).

1.1.4 Giant taro, *A. macrorrhiza*

Giant taro (Fig. 1.6, 1.7) probably originated in Sri Lanka or India, where it is still grown, and spread to Southeast Asia and the Pacific. It is a major staple and prestigious food in Western Samoa, Tonga, Wallis and Futuna and in some atoll countries (Sakai 1983). In other countries such as Solomon Islands and PNG, it is a reserve for use in times of famine (Bourke 1982). Twenty-two accessions are held in collections in the South Pacific (Jackson and Breen 1985). Giant taro grows well under evenly distributed high rainfall, since it cannot withstand waterlogged conditions or prolonged drought. It is a perennial, and planting and harvesting take place throughout the year. The corm grows above ground as a stem, typically about 1 m long, 15–20 cm diameter and weighs up to 18 kg (Fig. 1.6 and 1.7). The leaves as well as the

Fig. 1.5 Taro (*X. sagittifolium*) at Tenaru Research Station, Solomon Islands.

stem are eaten in Indonesia (Sakai 1983). Corms are harvested as needed from 6 months to 4 years after planting. The thick skin layer, which is usually acrid, is removed and if the flesh is also acrid, then special cooking techniques are required before it can be used (Sakai 1983; section 5.4). It is a very hardy plant that is resistant to most pests and diseases. Sakai (1983) reports that root sections from giant taro may keep away white ants that commonly would damage coconut seedlings grown as an intercrop. A possible explanation for this is given in section 5.5.

Fig. 1.6 Giant taro (*A. macrorrhiza*) growing at IRETA field station, Alafua, Western Samoa. One of our collaborators, Dr Jill E. Wilson, is pictured.

Fig. 1.7 Giant taro corms (stems) and much smaller taro *Colocasia* corms at Apia market, Western Samoa.

1.1.5 Giant Swamp Taro, *C. chamissonis*

The giant swamp taro (Fig. 1.8) probably originated in Indonesia. Its range now includes the Philippines and the Pacific from 18° north to about 20° south latitude. It is commonly grown in freshwater swamps or artificial pits excavated to reach the water table. It can be grown under difficult, often saline, swampy conditions where few other crops would survive (Sivan 1983). It is one of the few subsistence crops that can be grown in the atolls, where it is a major food crop and has high cultural significance especially in the countries of Micronesia (Sakai 1983). In Fiji, it is an important crop for people living in swampy lowland areas such as the Rewa River delta (Sivan 1983). It is an important reserve food, as it may remain in the ground almost indefinitely. There are more than 100 accessions located in Pohnpei State of the Federated States of Micronesia, Kiribati and Tuvalu (Jackson and Breen 1985). It is relatively free of pest problems, except for *Papuana* taro beetle which has caused severe losses in some areas (Sivan 1983). Like giant taro it is a perennial, hence planting and harvesting may be done at any time. Harvesting may occur in less than 1 year for some cultivars, or may be delayed up to 6 years and even longer. Commonly corms weigh 1–4 kg, but those that are very old, before being used for prestige purposes in celebrations, may reach 180 kg (Sakai 1983). The corms may be acrid and contain high levels of calcium oxalate (see section 5.3). The young leaves and young inflorescences are used as a vegetable in parts of the Philippines but not in Micronesia (Sakai 1983).

Fig. 1.8 Giant swamp taro (*C. chamissonis*) growing at Dodo Creek Research Station, Solomon Islands.

1.1.6 Elephant Foot Yam, *A. campanulatus*

This species can be distinguished from the other edible aroids described above by its dissected leaves (Fig. 1.9). It may have originated in India and is also present in Malaysia, Indonesia (Sastrapradja et al. 1984), Philippines, Melanesia and Polynesia, but is only of minor importance. It is sometimes fed to pigs in Indonesia and the

Philippines (Sakai 1983; Sastrapradja et al. 1984). It is a tropical and subtropical crop with crop duration of up to 4 years with annual harvesting, storage and replanting of cormels. No major pests or diseases affect the crop (Sakai 1983).

Fig. 1.9 Elephant foot yam (*A. campanulatus*) at Tenaru, Solomon Islands.

1.1.7 Yam, *Dioscorea* spp.

Yams are traditional food crops of great antiquity that originated in Africa, Asia and America, and are now widely distributed throughout the tropics, with a few members occurring in temperate zones (Coursey 1983b). World production in 1985 was 26 million t of which about 95% was grown in Africa (in the so-called yam belt of West Africa, particularly Nigeria where it is a staple crop), with the remainder spread throughout the tropical world, including PNG, Solomon Islands, Vanuatu amd Micronesia (FAO Production Yearbook 1985). The major species that originated in West Africa, and which are most important there, are *D. rotundata* and *D. cayenensis*, whereas *D. alata* (greater yam) and *D. esculenta* (lesser yam) originated in Southeast Asia and are the most important yams in the Asia-Pacific region. Greater yam is a prestigious food in parts of PNG, Fiji, Tonga, Vanuatu, Samoa, and the Federated States of Micronesia. Although worldwide there are probably 50–60 species of *Dioscorea* that are sometimes used as food plants, the four mentioned above are most commonly used (Coursey 1983b).

The yam is a perennial plant with long trailing vines (Fig. 1.10 and 1.11). The tubers mature in 6–10 months and when stored remain dormant for 3–6 months depending on species and cultivar. Yams grow best in deep, well-drained soils with a rainfall of 1000–3000 mm in the absence of frost. *Dioscorea alata* may be grown up to an altitude of about 2000 m (Bourke 1982). Average yields worldwide in 1984 over all species were 10.5 t/ha (FAO Production Yearbook 1985), but may range from <10 to >50 t/ha (Bourke 1982; Quin 1984). The tubers from the greater yam (*D. alata*) may grow to be very large, up to 3 m long and 60 kg in weight, whereas those of the lesser yam (*D. esculenta*) are more numerous (5–20), much smaller and are less fibrous than the larger tubers of other species. Yam tubers are fragile and need to be harvested with care if they are to store well during their period of dormancy. Storage usually occurs in well-ventilated sheds or at least under shade (Passam et al. 1982). Yams are vegetatively propagated from the tubers (about 20% of the previous crop is stored for planting), and perhaps as a result, many cultivars now only rarely flower. In the Pacific, there are about 1100 accessions, mainly of *D. alata* and *D. esculenta*, so far recorded in Vanuatu, PNG and Solomon Islands (Jackson and Breen 1985). There are five other species (*D. nummularia, D. bulbifera, D. pentaphylla, D. rotundata,* and *D. trifida*) that are of minor importance in the Pacific. In PNG yam is used in some areas as a co-staple food with sago, taro or bananas (Bourke 1982). Major disease problems occur with *D. alata* in Solomon Islands (Jackson and Liloqula 1979; Jackson 1980b) and in the East Sepik Province of PNG, whereas *D. esculenta* is a more rugged species (Quin 1984). One variety of *D. esculenta* (Asakua) in the East Sepik Province does not need to be staked (Quin 1984).

1.1.8 Cassava, *M. esculenta*

Cassava is a dicotyledonous plant, 1–3 m in height (Fig. 1.1. and 1.12), belonging to the family Euphorbiaceae. The plant originated in Brazil with Central America as a likely additional centre of origin (Onwueme 1978). Its world production of 136 million t in 1985 puts cassava in sixth place after wheat, maize, rice, potato and barley. It is widely spread throughout tropical Africa, Asia and South America, being particularly important in Brazil, Thailand, Indonesia, Zaire, and Nigeria (FAO Production Yearbook 1985). In the South Pacific it is the major root crop in Fiji and Tonga, whereas in PNG and most other countries it is a minor crop compared with sweet potatoes, taro and yam (Bourke 1982; van Wijmeersch 1986). However, cassava is increasing in importance, particularly in drier areas, because it is a hardy drought-resistant crop that can give acceptable yields on low-fertility soils (Rickard and Coursey 1981;

Fig. 1.10 Yam (*D. alata*) at Tenaru, Solomon Islands.

Fig. 1.11 Yam (*D. esculenta*) at Dodo Creek Research Station, Solomon Islands.

Fig. 1.12 Cassava tubers in foreground at Suva market, Fiji.

Bourke 1982; Thaman and Thomas 1982; Larsen 1984). It is reproduced from stem cuttings and requires weeding until a canopy is established (Fig. 1.1).

The root matures in 10–14 months, but is not harvested until required. The roots deteriorate after 1–3 days exposure to air in the tropics. The plant is unique in that its roots are not organs of dormancy and hence have no natural function in preservation of the plant through an adverse season (Coursey 1982). The poor storage qualities of cassava present a major problem (Rickard and Coursey 1981; Rickard 1985) and the approach of not harvesting it until required has the disadvantage that it keeps large areas of land occupied in storage of mature cassava (Coursey 1982). The average yield of cassava worldwide is 9.6 t/ha, which is less than for sweet potatoes and yams but greater than for taro (FAO Production Yearbook 1985). Pests and diseases of cassava are severe in Africa (Hahn et al. 1979) but in the Pacific the crop is apparently free of major problems (Bourke 1982). There are appreciable collections of cassava cultivars in Fiji, PNG, Solomon Islands and Vanuatu—about 150 accessions altogether.

A major problem with cassava is its cyanide content, in the free and bound forms (section 5.1). Fortunately, most of the cyanide can be removed by postharvest treatments and cooking (Conn 1973; Cooke and Coursey 1981). Cultivars of cassava may contain from 1 to >100 mg HCN/100 g fresh peeled tuber, and there are larger amounts present in the peel and the leaves. The South Pacific cultivars that we have studied contain about 1–9 mg HCN/100 g fresh weight (sections 3.7 and 5.1). These are called sweet cassava. Those containing large amounts of cyanide are bitter. The young leaves of sweet cassava are also used as vegetable greens, but not in the South Pacific. In iodine-deficient areas, consumption of cyanide-containing cassava exacerbates the incidence of endemic goitre and cretinism. It also causes neurological diseases (section 5.1). Another problem for human nutrition is the low protein content of cassava (Table 3.15).

1.2 Nutrition

1.2.1 Comparison of Tropical Plant Foods

A comparison is made (Table 1.1, Fig. 1.13, 1.14) between the major components of the diet (energy, protein, minerals and vitamins) obtained from root crops and those from the tropical cereal (rice), legumes (beans), and a tropical green vegetable (taro leaves). For the sake of simplicity, other important staple foods of the South Pacific such as sago, bananas and breadfruit have not been included. The energy values in Table 1.1 should be read in conjunction with the moisture content, because for those foods which contain low amounts of fat and dietary fibre, there is an inverse linear relation between energy and moisture (Bradbury 1986; section 2.9). Thus, the root crops have lower energies than rice because of their much higher moisture contents, but after boiling the moisture contents of rice and beans are about the same (70%) (Paul and Southgate 1979) as that of boiled sweet potato or cassava (see section 4.3). Clearly, the boiled root crop has about the same energy content as boiled rice, and

Table 1.1. Comparison of nutrient content of different uncooked foods.[a]

	Sweet potato tuber	Cassava tuber	Yam *D. esculenta* tuber	Taro *Colocasia* corm	Rice polished raw	Beans (kidney, lima or mung), dried	Taro edible green leaves
Moisture %	71	63	74	69	12	12	85
Energy (kJ/100 g)	460	610	414	490	1500	1200	110
Protein %	1.4	0.5	2.0	1.1	6.5	22	4.2
Percentage of energy of food provided by protein (PE%)	5.3	1.5	8.5	3.9	7.2	31	65
Dietary fibre %	1.6	1.5	1.2	1.5	2.4	22	5.0
Minerals (mg/100 g)							
Ca	29	20	8	32	4	100	182
Fe	0.4	0.2	0.8	0.5	0.5	8	0.6
Vitamins (mg/100 g)							
Vitamin A (rentinol equiv)[b]	0.01	tr	0.02	0.01	0	0.008	0.5
Thiamin	0.09	0.05	0.05	0.03	0.08	0.5	0.14
Riboflavin	0.03	0.05	0.03	0.03	0.03	0.2	0.3
Nicotinic acid (total)[c]	0.6	0.6	0.4	0.8	3.0	2	1.0
Vitamin C (ascorbic acid)	24	15	20	15	0	tr	37
Reference[d]	a	a	a	a	b	b,d	c,e
World production, 1985 million t/year, ref. f[d]	11	136	all yams 26	all taro 5.6	466	nk	nk

[a] Selected values on basis of fresh weight; nk = not known; tr = trace.
[b] Vitamin A is equal to the sum of retinol + β-carotene /6. White sweet potatoes as given in the table contain small amounts of β-carotene, but yellow varieties contain a large amount (ref.b).
[c] Total nicotinic acid equals nicotinic acid + tryptophan/60.
[d] References: a, Table 3.15; b, Paul and Southgate 1979; c, Table 3.4; d, South Pacific Commission 1983; e, Wenkam 1983; f, FAO Production Yearbook 1985.

Fig. 1.13 Comparisons of the energies and protein, calcium and iron contents in the four major tropical root crops and typical cereals, legumes and edible green leaves.

more than that of beans and other legumes (because of their high dietary fibre content; Bradbury 1986) and much more than that of edible green leaves, because of their high moisture and fibre content. Among the root crops cassava has the highest energy and yam the lowest energy as shown in Fig. 1.13. Legumes are the best source of dietary fibre followed by edible green leaves, root crops and cooked rice.

An indication of the adequacy of a food as a source of protein may be obtained by calculating the percentage of the total energy of the food provided by protein (PE%). This is simply calculated by the relation

$$PE\% = 17 \times 100 \times \%\ \text{protein/energy},$$

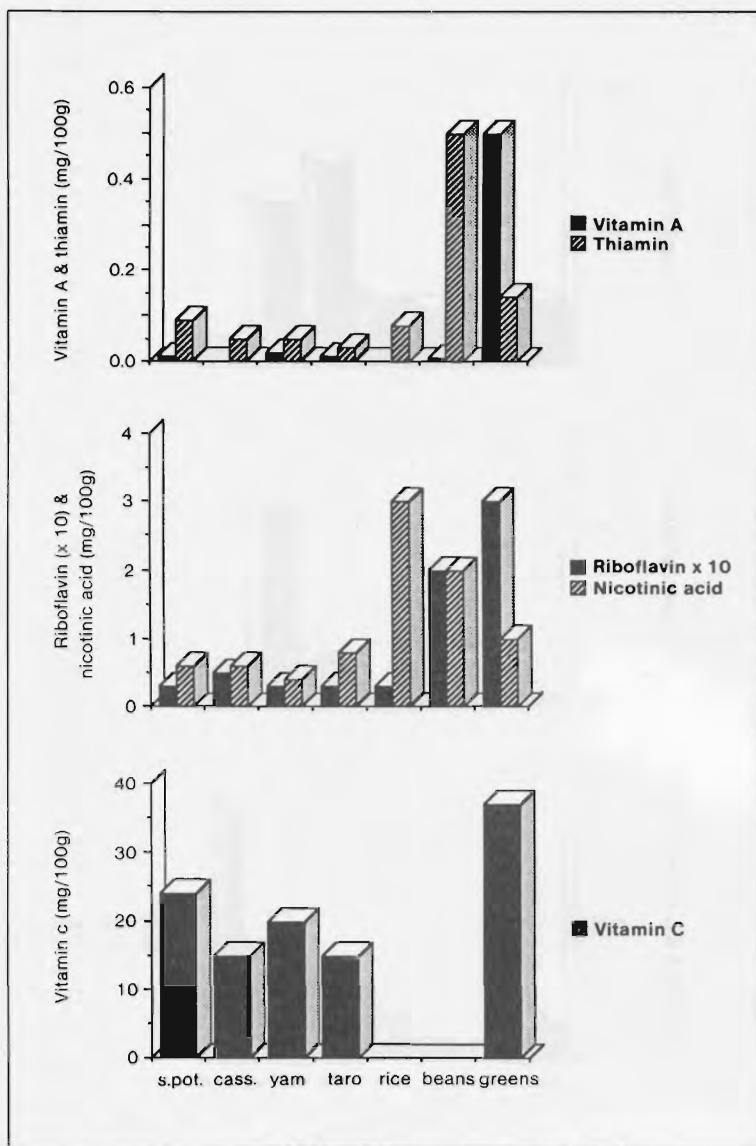


Fig. 1.14 Comparisons of the major vitamins in the four major tropical root crops and typical cereals, legumes and edible green leaves.

where energy is expressed in kJ/100 g and the factor 17 is the energy (kJ) produced by the metabolism of 1 g of protein (Atwater factor; Passmore and Eastwood 1986). Most satisfactory diets provide 10–15% of the energy from the protein present in the food. On this basis it is clear from Table 1.1 that edible green leaves and beans are excellent sources of protein, whereas yam and rice are marginal sources and the other root crops are inadequate; this is particularly true for cassava. It should be noted, however, that the values of PE% reported by different workers for the same food show considerable variation. For example, cassava and taro are reported as 3.3 and 6.8 by Passmore and Eastwood (1986), whereas we have obtained 1.5 and 3.9 respectively. Our lower values

are due to the lower protein content that we found for cassava (Table 3.14) and taro (Table 3.3) compared with other workers. The use of PE% as a measure of the adequacy of a diet with respect to protein is fraught with difficulties which are discussed elsewhere (FAO/WHO/UNU 1985), but the general conclusion that most of the root crops are inadequate sources of protein is probably correct.

Huang (1982) found that growing teenage boys were unable to maintain nitrogen balance on an intake of sweet potato that gave 0.69g protein/kg body weight. On the other hand, adults fed about 2.5 kg of sweet potato/day supplemented by a small amount of fish and vegetables (0.63 g protein/kg weight) showed no signs of protein deficiency after 2 months. Huang (1982) concluded that a diet solely of sweet potato did not maintain adequate protein nutrition in subjects of growing age. Clearly, a root crop diet of cassava, taro or sweet potato requires supplementation with foods of higher protein content, as discussed in section 1.2.2.

The calcium content of edible green leaves of taro is higher than that of other edible green leaves such as from sweet potato (Table 3.1), because of the large amounts of calcium oxalate present in taro leaves (section 5.3). The calcium content of legumes is also high, and that of the roots and tubers of sweet potato, cassava, yam and taro is still acceptable, whereas that of rice is low (Fig. 1.13). The iron content of legumes is much higher than in all other foods, which are about equal except for cassava which is lower. For the two minerals taken together, legumes appear to be the best source, followed (in general) by edible green leaves, root crops and finally polished rice.

With regard to vitamins, the edible green leaves are the best source with adequate amounts of all vitamins listed, followed by root crops and legumes which each show small amounts of two vitamins and finally polished (white) rice which is missing three vitamins (Fig. 1.14). Brown rice is to be preferred to white rice in this regard because of retention of the germ and the aleurone layer, both rich in thiamin and nicotinic acid (Bradbury et al. 1984b; Passmore and Eastwood 1986).

A short summary of the situation is as follows:

Energy	rice (boiled) ~ *root crops* ~ legumes > edible greens
Protein	legumes > edible greens > rice (boiled) > *root crops*
Minerals (Ca, Fe)	legumes > edible greens ~ *root crops* > rice
Vitamins	edible greens > *root crops* ~ legumes > rice

Thus, compared with the other plant food groups, root crops are a good source of energy, an average source of minerals and vitamins and the poorest source of protein. The variability of the protein content of different cultivars of the same root crop is large (section 7.1), and in the case of sweet potato there have been attempts to breed for increased protein content (Li 1982).

1.2.2 Nutrition in the South Pacific

In general, the traditional diets of the peoples of the South Pacific are based on root crops, yet there are very wide differences between subsistence diets in various countries and in different parts of the same country. The subsistence diet in a particular place clearly depends on a range of local environmental factors including climate, altitude, distance from the sea and vegetation (Oomen 1971; Parkinson 1982; Keig et al. 1983). These factors and others including cultural preferences, food taboos and population density are just some of the constraints that determine the nutritional status of the people. Since the conditions in PNG are in some ways different from those of the rest of the region, we will consider them separately.

Papua New Guinea There are many different physical environments or ecological zones in PNG. They are distinguished from one another by environmental

parameters such as landform, mean annual rainfall and altitude (Keig et al. 1983). The physical environment (e.g. coastal, riverine, upland or highland, flat or hilly) partly determines what crops will grow. Thus, in the coastal area and along the big rivers, the staple food is usually the sago palm (*Metroxylon* spp.) from which high-starch, low-protein sago is produced (Wina et al. 1986). Fish, shellfish and crustaceans are available at the coast, but these high protein sources may not be available to people living only 5 miles inland. In other lowland situations the staple may be taro (Ferro-Luzzi et al. 1975) or yam and sweet potato (Heywood and Nakikus 1982). In upland and hilly regions yam is of importance in drier areas and taro *Colocasia* and *Xanthosoma* with bananas in wetter areas, whilst in the Highlands the staple food is sweet potato (Oomen et al. 1961). In all regions there is a variety of edible green leaves. Secondary foods include fruits (bananas, coconut, breadfruit, papaya), legumes and seasonal supplies of nuts. There is also a wide variety of protein-rich food that includes insects, reptiles including snakes and crocodiles, many small animals including bandicoots and rats, dogs, fish and eels (Parkinson, S., pers. comm.). Dwyer (1985) reported that one community in Southern Highland Province averaged 6 g protein/person/day over 1 year from medium-sized mammals. These secondary foods provide important supplements of protein, vitamins and minerals, and increase the attractiveness of an otherwise starchy and monotonous diet. However, their contribution is often seasonal and/or irregular.

There is a continual slow change in the diets of the people due to: (1) a reduction in the amount of taro *Colocasia* and an increase in the amount of sweet potato and taro *Xanthosoma* (Bourke 1983); and (2) an increase in the extent of imported foods (Harvey and Heywood 1983). Allowing for this slow change, Jenkins et al. (1984) considered that the diet of the rural 90% of the PNG population in 1984 was still largely traditional, and that where significant amounts of imported foods were consumed (rice and tinned meat or fish) improved nutrition was evident.

There have been many food and nutrient intake studies in various regions of PNG over about 30 years (reviewed by Heywood and Nakikus 1982). Some of these show low intakes of energy and also, tentatively, that the amount of protein in many areas may be low. Similar conclusions were obtained from a study of children in two contrasting environments near the coast and in the Highlands, many of whom showed a deficit of energy and of protein intake on an age basis or a smaller deficit if calculated on a basis of intake/kilogram of body weight. There was, however, a low incidence of clinical signs of nutritional deficiencies and it was concluded that the high proportion of nutritionally inadequate diets (assessed using Caucasian populations as standards) did not match with the low levels of physiological or clinical signs and symptoms of malnutrition (Ferro-Luzzi et al. 1975). However, in 1972 throughout PNG, malnutrition was the fifth most common diagnosis and cause of death in children under 5 years of age, and the infant mortality rate of 106/1000 in 1974 was similar to that of other developing countries (Korte 1975).

A more recent survey in 1981 in Simbu Province of the Highlands, which had been studied over a 25-year period, showed an improvement, to adequate levels, of intake of energy and particularly of protein, and an associated increase in the growth rate of children. This improvement was due to availability of income from cash cropping and consequent purchase of store foods (e.g. cereals, tinned fish and tinned meat). This undoubted improvement in nutrition has been at the cost of increased dependency on imported foods, which has adverse economic repercussions in PNG and may possibly lead to an increase in chronic degenerative diseases in adults in the future (Harvey and Heywood 1983). In 1983–84 a National Nutrition Survey was conducted throughout PNG, and about 40 000 children under 5 years of age had their

recumbent length, weight and mid-upper-arm circumference measured (Heywood and Singleton 1984).

Islands of the South Pacific The traditional diet of the peoples of the South Pacific Islands depended greatly on the climate, geographical location and fertility of the land. Parkinson (1982) described three different types of diet found in (1) coastal, river delta and lowlands, (2) highlands, and (3) atolls. In coastal areas, river deltas and lowlands, nutrition was good due to an adequate supply of root and tree crops (sago, coconut), edible green leaves as well as fish, shellfish, birds and small animals. The food supplies of the inland (Highland) people was, as in PNG, more limited to root vegetables, fruits and nuts with edible green leaves as a major source of protein and with very limited supplies of animal foods. In the atolls the staple foods were bread-fruit and giant swamp taro (*Cyrtosperma*) supplemented in high rainfall areas by coconuts, bananas, taro and sweet potatoes, and in lower rainfall areas by pandanus. Fish and shellfish provided a good source of protein, but fruits and green vegetables were scarce. Traditional foods provided a reasonably balanced diet except for the possibility of a shortfall of protein in the highlands, of vitamins (due to lack of edible green leaves and fruit) in the atolls, and the fact that the bulkiness of the diet made it difficult for small children to achieve a reasonable intake of energy and protein (Binns 1975; Parkinson 1982).

Anaemia, a condition which occurs when the concentration of haemoglobin present in the blood falls below a certain level, is very prevalent particularly amongst women and children in tropical countries, and is common throughout the South Pacific. Nutritional anaemia may be due to a deficiency of iron, folic acid, vitamin B_{12} and/or other nutrients such as protein and ascorbic acid (Passmore and Eastwood 1986). The most common cause of nutritional anaemia is a shortage of iron, and infections such as hookworm and malaria that result in loss of blood also cause and exacerbate the disease. Legumes, dark green leaves (Table 1.1), shellfish, red-fleshed fish and birds eggs are good sources of dietary iron. The traditional diets in the Pacific Islands were probably adequate in this respect.

The traditional diets of the people of the South Pacific Islands are rather similar to those already described for PNG, except for the atoll diet, which is distinctly different. However, whilst the PNG diet has changed only slowly over the last 30 years (see above), that in the Islands has undergone more rapid change through the importation of foods, particularly of cereals, sugar, tinned meat and fish (Parkinson 1982; Thaman 1983; Pollock 1983). Furthermore (as in PNG) the production of taro *Colocasia* has decreased in Fiji from 28% of the total root crop production in 1968 to 17% in 1978 and that of cassava has increased over the same period from 57 to 77% (Sivan 1983). This replacement is unfortunate because not only is the cassava tuber nutritionally inferior to the taro corm (see section 3.8), but taro leaves are also one of the few traditionally important green vegetables in the region (Parkinson 1982; Thaman and Thomas 1982; Sivan 1983).

Changes in the diet of the South Pacific islanders are not easy to quantify (Pollock 1983), but have resulted in increased consumption of animal fat and protein, refined sugar and salt and decreased intake of dietary fibre and possibly vitamins (Parkinson 1982; Taylor 1983; Pollock, N.J., 1988, pers. comm.). This dietary change, as well as an increase in bottle feeding of babies, increasing urbanisation and other factors have probably resulted in increases in obesity, diabetes, heart disease, dental caries, anaemia, gout, diarrhoea, food allergies and childhood malnutrition in the region (UNDP 1982; Taylor 1983; Parkinson and Lambert 1983; Thaman 1983). Heart attacks and strokes are now the major causes of death amongst adults in Fiji and a number of other Pacific Island countries (Parkinson and Lambert 1983). In the 1970s

the diabetes prevalence rate in the highly urbanised island of Nauru was 44% among those aged 20 and older, in urban Funafuti, Tuvalu, it was 10% (the two worst cases), and it was an increasing health problem in the Cook Islands, Tonga and Western Samoa (Ward and Hau'ofa 1980). Recent research has shown that traditional foods are digested more slowly than western foods and the possible presence of a thrifty gene amongst Polynesians and certain other racial groups has been postulated (Thorburn et al. 1987).

Sufficient examples have been given to indicate that deleterious changes have occurred in recent years in the nutrition of the people of the South Pacific and that these changes can generally be attributed to indiscriminate use of imported western foods. From the economic point of view, food imports are a major item in the trade figures of every island community and trade deficits are widespread. A wide-ranging series of recommendations on the problem have been put forward, which have included proposals for increased local production of food crops, promotion of home and school gardens (Gershon 1986), and increased education in the proper use of foodstuffs (UNDP 1982; Parkinson and Lambert 1983).

1.3 Chemical Composition in Relation to Nutrition and Agriculture of Root Crops

In order to relate food intake studies to the amount of energy, protein, minerals and vitamins that are actually absorbed by the human body, it is necessary to know both the chemical composition and the degree of absorption by the body of the various components of the foods that are eaten. The absorption is normally greater than 90% for protein, fat and carbohydrate, but may be as low as 1% for iron, particularly iron from plant sources (Passmore and Eastwood 1986). The degree of absorption of nutrients by the body is an aspect of human nutrition that will not be addressed here, but attention will be focused on the chemical composition of the root crops.

A considerable amount of information on the chemical composition of root crops has been obtained by food analyses carried out over a period of about 50 years. Peters (1957) produced a useful bibliography of early work. Since then, more results have been obtained which are reviewed in Chapter 3 for each of the root crops, together with the results of the work produced by the ACIAR/ANU Program on Nutrition of Tropical Root Crops in the South Pacific (Bradbury et al. 1985a). Much of the data already available has been obtained from cultivars used in other parts of the world, and one aspect of the present program has been to obtain data on cultivars locally important in countries of the South Pacific. Thus, for example, the yellow sweet potatoes popular in North and Central America have a much higher content of β-carotene (100–200 times greater) and a higher sugar content than the white sweet potatoes which are popular in the South Pacific (Singh and Bradbury 1987).

In the older analyses carbohydrate was usually obtained by difference and separate analyses were not made for starch, sugar and dietary fibre. Amino acid analyses were not recorded for *Xanthosoma*, *Alocasia* and *Cyrtosperma* corms, there were no analyses available for potential antinutritional factors such as calcium oxalate in these aroids and for trypsin inhibitor in all the root crops. Also, there were only a limited number of analyses on the edible leaves of taro, sweet potato and cassava. Faced with this situation, it was clear that full chemical analyses were needed on the popular cultivars of the various root crops for countries of the South Pacific. Samples were therefore obtained from research stations, local gardens and from local markets by

collaborators in Fiji, Kiribati, PNG, Pohnpei (Federated States of Micronesia), Solomon Islands, Tonga, Vanuatu, and Western Samoa, and were sent to Australia for analysis.

Another important aspect concerned the effects of cooking on the nutrient content of the root crops. Some information was available in the literature on this subject mainly for sweet potato and cassava (see Chapter 4), but it was considered important to study the effects of particular methods of cooking, some of which may be unique to the region, on the major root crops of the South Pacific.

Because of the large variability in chemical composition of root crop tubers (see section 7.1), it is possible, for example, for people to be eating a staple diet of sweet potato which has a protein content that is far lower than the accepted mean value used for nutritional calculations. We have identified such a case with 12 sweet potato cultivars from the Kaintiba District of PNG, where the mean protein content over 54 samples was 0.62% (Appendix Table A.13; section 6.2.4). The average protein composition of these tubers was less than half that of the accepted average used for nutritional calculations, and would clearly represent a large source of error in dietary uptake studies if the accepted average was used. It highlights the need for a cautious approach to the interpretation of dietary uptake studies as discussed by Heywood and Nakikus (1982). This particular source of error would be eliminated if the actual food consumed in the survey was subjected to chemical analysis, as was done in studies in PNG by Ferro-Luzzi et al. (1975,1978) and Norgan et al. (1974, 1979).

The variability in chemical composition of root crops is clearly useful for the plant breeder who may wish to select/breed for a combination of desirable characteristics such as high yield, disease and pest resistance, high protein content and acceptability as food. Taking protein content as an example, one may ask what fraction of the low protein content recorded for the Kaintiba sweet potato mentioned above was due to inferior cultivars and what fraction to poor environmental conditions during growth. Literature studies of the effect of environmental constraints on yield and chemical composition are discussed in Chapter 6 as well as our own studies on sweet potato, yam (*D. esculenta*) and the edible aroids.

The antinutritional factors studied in these root crops are cyanide present in cassava, trypsin and chymotrypsin inhibitors in all root crops, insoluble calcium oxalate, and the acrid factor of the edible aroids. Mason (1956) reported that the South Pacific cassava cultivars were generally low in cyanide and our results given in section 3.8 confirm this assessment. Nevertheless, there are several medical conditions that may result from continued ingestion of cyanide from cassava (see section 5.1). Trypsin and chymotrypsin inhibitors present in tubers and corms are capable of inhibiting the action of the major proteinases of the gut, thereby reducing the digestion of protein. This would present a problem in the feeding of uncooked tubers and corms to animals, but fortunately these inhibitors are inactivated (denatured) by prolonged cooking. A detailed study has been made (Hammer 1987; see also section 5.2). The amount of insoluble calcium oxalate and water soluble oxalate has been determined in the root crops (Holloway et al. 1988; see also section 5.3). Acridity in aroids causes swelling of the mouth and throat. The discomfort produced prevents the full utilisation of the uncooked taro plant by animals (Sakai 1983), and if the acridity is not properly removed by cooking, it is a deterrent to its use by humans. This problem is discussed in section 5.4.

Chapter 2. Experimental Methods

In this chapter the methods used in sample preparation and chemical analysis are described. *All results recorded in this monograph are calculated on the basis of the fresh weight of the sample.*

2.1. Sample Collection

Fresh root crops were harvested from agricultural research stations, farmers' fields or in some cases they were purchased in the market. The source countries were Fiji, Kiribati, Papua New Guinea, Pohnpei (Federated States of Micronesia), Solomon Islands, Tonga, Vanuatu and Western Samoa. The names of the various collaborators in each country are listed elsewhere. The agricultural details pertaining to the conditions of growth of each crop are given in the particular Appendix table containing the chemical data. After harvesting, the tubers or corms were washed to remove all soil, dried in air and weighed to three significant figures to obtain the fresh weight. Sweet potato, taro and yam were wrapped in clean, dry paper and packed in cardboard boxes. Cassava tubers were placed in layers in cardboard or wooden boxes and surrounded by moist vermiculite. The boxes were consigned by air-freight to Canberra, Australia, where they were normally received in good condition within 2–7 days. They were either processed immediately or were stored from 1 to 14 days in a cool room maintained at 15 °C.

2.2 Sample Preparation

The tuber or corm was weighed just before processing to determine the weight loss that occurred during transport and storage. It was peeled and any diseased material was removed. With the smaller tubers or corms the whole sample was used, but with the larger samples three slices or discs of about 100 g each were taken (one from each end and one slice from the middle) and bulked together. This sampling procedure allowed for any longitudinal and radial gradients of composition within the tuber or corm (section 3.9) and has been used for cassava (Cooke 1978), taro (Wills et al. 1983) and in a modified form for yam (Ologhobo 1985). All samples were shredded using a food processor and about 100 g was stored at –20 °C. Two accurately weighed samples (about 10 g) of the freshly shredded material were dried at 40 °C until constant dry weights were obtained after about 4 days. A similar drying procedure at 100 °C was also carried out, from which the total moisture content of the fresh material was calculated.

The bulk of material was dried at 40 °C and was ground to a fine white powder using an electric grinder. This ground material stored well in bottles and contained a known small amount of residual moisture, as compared with the material dried at 100 °C. The material dried at 40 °C was used in all analyses except for determination of vitamin C and free and bound cyanide.

2.3 Sampling Procedures

In much of the earlier work, duplicate analyses were made on single tubers or corms, or on multiple tubers or corms of a particular cultivar that had been bulked together and treated as a single sample. Assuming that the bulking procedure included thorough mixing of the dried material, then the final analytical result represented an accurate mean value. No measure could be obtained, however, of the variability of composition of tubers within the one cultivar and hence it was not possible to test statistically for differences between different cultivars. This problem was overcome by carrying out later analyses on 3–10 tubers or corms of the same cultivar. Such analyses showed that the differences between tubers or corms of the same cultivar were usually much greater than the analytical variance of the analysis (section 3.1).

2.4 Moisture Analysis

As already indicated in section 2.2, the moisture loss of the tuber or corm during transport and storage was measured and duplicate 10 g samples of shredded material were dried to constant weight at 100 °C. The total moisture content of the fresh tuber or corm was calculated from the loss in weight during transport and storage (usually about 10%) and the further loss in weight during drying at 100 °C.

2.5 Nitrogen Analysis

The organic nitrogen content was determined routinely by the Kjeldahl procedure, but some samples were also analysed for total nitrogen using an automatic CHN analyser (Dumas method) by the Analytical Group in the Research School of Chemistry, Australian National University (Bradbury et al. 1985b). There was good agreement between the results of the two methods which showed that inorganic nitrogen-containing compounds such as nitrate were absent from sweet potato. The Kjeldahl method was more reproducible than the Dumas method (section 3.1). The Kjeldahl method described below was expedited by use of the Kjeltec digestion and distillation apparatus. To the dried sample (0.1 g) was added 2 ml of digestion mixture (187 g of K_2SO_4 in 250 ml of conc H_2SO_4) and 0.5 ml of mercuric sulfate solution (13.7 g in 100 ml of 2M H_2SO_4). The mixture was heated at 450 °C for about 10 min in the Kjeltec digester until a clear solution was produced. The tube was placed in the Kjeltec distillation apparatus and 10 ml of a solution which contained 5 g NaOH + 0.5 g $Na_2S_2O_3 5H_2O$ was added. The ammonia from the sample was steam-distilled for 5 min into a receiver flask, which contained 5 ml of a solution of boric acid and indicator. This latter solution was made by dissolving 20 g H_3BO_3 and 0.0067 g methylene blue in water, 0.0133 g methyl red in 10 ml ethanol, mixing the solutions and making up to 1000 ml with water. The ammonia in the receiving flask produced by the breakdown of organic nitrogen-containing compounds in the sample was titrated with standard 0.01 M potassium biiodate ($KH(IO_3)_2$) until the indicator solution changed from green to blue at the end point (McKennie and Murphy 1970). This allowed calculation of the percent nitrogen in the dry sample and in the fresh sample.

2.6 Protein Content and Non-Protein Nitrogen

The crude protein content, which is hereafter called simply the protein content, was calculated by the equation

$$\text{protein content (\%)} = \text{\% nitrogen} \times 6.25. \quad (1)$$

The factor of 6.25 is the standard agreed factor used for all foods with the exception of some specially designated foods such as some cereals, nuts, milk and other products (Paul and Southgate 1979). The value of 6.25 is based on the assumption that the protein contains 16% nitrogen, but in fact the nitrogen content of the protein is dependent on its amino acid composition. The second difficulty with the use of equation (1) is that some of the nitrogen present in the root crop is not combined as protein and this is called non-protein nitrogen. For example, with sweet potato about one-quarter of the total nitrogen is present as non-protein nitrogen (Tamate 1985) and about 80% of this occurs as amino acids (Purcell and Walter 1980; Tamate 1985). Thus, since the bulk of the non-protein nitrogen is present as amino acids, there is little *dietetic* error involved in the use of total nitrogen to calculate protein, although the true protein content is in fact overestimated.

2.7 Lipid Analysis

A dried sample (5 g) was weighed into an extraction thimble which was immersed in 50 ml boiling diethyl ether for 10–15 min and then raised above the boiling solvent and extracted for a further 20–25 min. The ether was then removed from the extraction flask and the weight of ether insoluble material obtained. The lipid content was calculated as a percentage of the fresh weight of the sample.

2.8 Analysis of Starch

After removal of sugars by extraction with 80% ethanol, the starch content of the sample was determined by gelatinisation of the starch at 100 °C, followed by its hydrolysis to glucose at 60 °C, catalysed by α-amylase and amyloglucosidase and finally colorimetric determination of glucose. This was a modification of the AOAC (1984) method used for determination of starch in cereals. A dry sample (0.5 g) was blended with 40 ml of 80% ethanol (v/v) in a Polytron (Kinematica, GMBH Luzern-Schweiz) for 2 min. The resultant slurry was filtered and washed once with 80% ethanol. The slurry was transferred to a 100 ml standard flask and heated at 100 °C for 30 min with intermittent shaking. The solution was cooled at 60 °C and 5 ml of 0.1% α-amylase (Sigma) and 1.0 ml of amyloglucosidase (1400 units/ml, Sigma) was added and the mixture heated at 60 °C for 45 min. The mixture was cooled and made up to 100 ml with water (suspended material used for dietary fibre analysis; section 2.9). About 30 ml of this solution was centrifuged at 5000 rpm for 30 min and 0.5 ml of the supernatant diluted to 50 ml with water. Two millilitres of the diluted solution was then added to 2 ml of the reagent (10 mg *o*-dianisidine (3,3 '-dimethoxybenzidine) dihydrochloride, 10 mg of horseradish peroxidase and 0.40 ml glucose oxidase (1100 units/ml), that had been equilibrated at 30 °C. After mixing and reacting for 30 min the reaction was stopped by adding 10 ml of H_2SO_4 (25% v/v). The absorbance of each solution was then determined at 540 nm. The method was always calibrated by use of five different glucose standard solutions and the percent glucose converted to percent starch by multiplication by 0.90.

2.9 Dietary Fibre

The fibre content of the root crops was determined by a modification of the neutral detergent method (Holloway et al. 1977). Nonfibre material was removed from the suspension from the starch analysis (see section 2.8) with 100 ml of a neutral detergent solution. The latter was made by dissolving 30.0 g of sodium lauryl sulfate, 18.6 EDTA $2H_2O$, 6.81 g $Na_2B_4O_7 10H_2O$, and 4.65 g Na_2HPO_4 in water, adding 10 ml

of ethylene glycol and making up to 1000 ml with water. After refluxing for 1 hour the suspension was filtered while hot through a No. 2 sintered glass crucible and washed with water and acetone. The crucible which contained fibre and ash was dried at 100 °C overnight and weighed. The fibre was removed by heating the crucible at 550 °C for 3 hours and the weight of the crucible plus ash was obtained. The difference between these two weights equalled the amount of dietary fibre present in the sample.

2.10 Total Sugar

The total sugar content was determined using a modification of the anthrone method (Holloway et al. 1985). The free sugars were extracted from 0.5 g of dried root crop (0.1 g in the case of sweet potato) with three extractions of 25 ml each with hot 80% ethanol/water at 60–70 °C. The combined ethanol extracts were filtered and made up to a total volume of 100 ml with 80% ethanol. The anthrone reagent was prepared by dissolving 200 mg of anthrone in 400 ml of sulfuric acid (560 ml conc H_2SO_4 added to 240 ml water). The anthrone reagent (4.5 ml) was cooled in ice and 0.1 ml of the ethanol extract added. The solution was mixed, cooled in ice and then the tube placed in a boiling water bath for exactly 7 min. It was cooled in ice and the absorbance measured at 625 nm. The total sugar content was determined using a series of four sucrose solutions (25–100 μg/0.1 ml) as standards in each run.

2.11 Content of Individual Sugars

The individual sugars were determined by a modification of the HPLC method described by Tamate and Bradbury (1985). Dry root crop (5 g) or fresh root crop (15 g) was blended with 35 ml of 80% ethanol and the solution filtered. The residue was then extracted three times with 10-ml aliquots of hot 80% ethanol. The extracts were pooled and the volume reduced to about 5 ml using rotary evaporation at $\not>$ 40 °C. Water (HPLC grade) was added to make the volume to 10 ml. A sample (about 0.5 ml) was filtered through an 'Acrodisc,' and 50 μl injected into the Waters HPLC system. The column was a radial-pak Si cartridge which fitted into a Z-module and the solvent used was 75% acetonitrile, 25% water and 0.2% SMI modifier at a flow rate of 1.4 ml/min (Egan et al. 1981). The individual sugars were detected by a differential refractometer and peak areas were used for quantitation compared with a standard mixture (1.0 g/ 100 ml) of each of fructose, glucose, sucrose, maltose and raffinose (Tamate and Bradbury 1985).

2.12 Energy Calculated from Protein, Fat, Starch and Sugar Contents

The energy content E_a (kJ/100 g) of the root crop sample was calculated by the following equation

$$E_a = 17b + 38c + 17e + 16f$$

where b = percent protein, c = percent fat, e = percent starch and f = percent total sugar present in the sample. The so-called Atwater factors (kJ/g) were; for protein 17, fat 38, starch 17 and sugar 16 (FAO/WHO/UNU 1985). The contribution of organic acids (oxalate, citrate, malate and succinate) to the energy of the root crop amounted to about 10 kJ/g of organic acid (Paul and Southgate 1979), but was not included because analyses were made for organic acids only on selected samples of each root

crop. Inclusion of the energy contribution from organic acids would have increased the energy by 2 kJ/100 g for yams up to a maximum of 14 kJ/100 g for elephant foot yam.

2.13 Energy Calculated from Moisture Content

Bradbury (1986) showed that for samples of food which contained only small amounts of fat and <3% dietary fibre, the energy E_b was inversely related to percent moisture content M, by the empirical relationship

$$E_b = -17.38\ M + 1699.$$

Values of E_a and E_b were calculated wherever possible from the data in the book. In many cases the average energies calculated from the moisture content were higher by about 10% than those obtained using the Atwater factors, although in a few cases both methods gave essentially the same result. Allowance for organic acids would have increased E_a somewhat and the values of E_b are slightly overestimated because of the appreciable amounts of dietary fibre and ash, and low amounts of fat present (Bradbury 1986). Thus the values of E_a and E_b given in the Appendix tables were averaged to get rounded values for the comparative tables in Chapter 3.

2.14 Ash Analysis

A 2-g sample of dried root crop was placed in a crucible and ignited at 550 °C for $\nless$ 4 h (normally overnight). The crucibles were cooled to about 100 °C in air, then to room temperature in a desiccator and weighed.

2.15 Atomic Absorption Analysis of Calcium and Iron

The ash obtained by ignition (section 2.14) was dissolved in 5 ml of 3 *M* HCl and the solution made up to 25 ml with distilled water. The amount of iron was determined using a Varian 1275 atomic absorption spectrometer and the system was calibrated against solutions of known concentrations prepared by quantitative dilution of an iron standard solution (Merck).

Because of the much greater amount of calcium than iron in the samples, the 25 ml solution used for iron was diluted 100-fold as follows: The solution (0.25 ml) was added to 5 ml of lanthanum solution (15 000 ppm) and was made up to 25 ml with water (AOAC 1984). The absorbance of this solution was compared with that of a series of calcium standards in the range of 0–5 ppm, prepared from dried calcium carbonate (Analar, B.D.H.).

2.16 Mineral Analyses by Inductively Coupled Argon Plasma Emission

Dry root crop (1 g) was ashed at 550 °C (section 2.14), dissolved in 5 ml of 5 *M* HNO_3 and the solution made up to 25 ml with distilled water. An inductively coupled argon plasma emission spectrometer located at the University of New South Wales was used (Lee 1981; Thompson and Walsh 1983). Analyses in duplicate were made for calcium, phosphorus, magnesium, sodium, potassium, sulfur, iron, copper, zinc, manganese, aluminium and boron by Mr R. Finlayson at the University of New South

Wales, using an inductively coupled plasma spectrometer (model 'Labtam,' International Plasma Lab., Melbourne, Australia). Standard solutions in 1 *M* HNO_3 of these elements were prepared and these were included as check standards amongst the samples determined. For calcium and iron there was also a direct comparison between the results determined by atomic absorption and those obtained by the inductively coupled plasma (ICP) method.

2.17 Vitamin A and Vitamin D_2

Vitamin A (retinol) commonly occurs as an ester in foods and is normally saponified by alcoholic potassium hydroxide prior to its analysis (Dennison and Kirk 1977; Singh and Bradbury 1988). The root crops usually contain the provitamin β-carotene, but no appreciable amounts of α-carotene (Singh and Bradbury 1988). Another possible provitamin (β-cryptoxanthin) was shown to be absent from a range of vegetables including sweet potato (Bureau and Bushway 1986) and hence was not studied.

The method used was based on Singh and Bradbury (1988). The root crop dried at 40 °C (5 g) was saponified in 10% KOH in alcohol-water (50:50) at 80 °C for 1 hour. After filtration the solution was extracted with hexane and the organic layer dried, evaporated to dryness and the residue dissolved in the HPLC mobile phase of methanol-acetonitrile-water (40:40:20). Separation on the HPLC was achieved using a 5 μ C18 steel column. Retinol and β-carotene were detected at 325 and 452 nm respectively, using a dual-wavelength UV absorption detector and dual-pen recorder.

Recoveries of authentic compounds of retinol, α-carotene, β-carotene and vitamin D_2 which were added to the root crop sample before saponification were greater than 90%. However, there was no retinol, α-carotene or vitamin D_2 present in any of the root crops analysed. The vitamin A content was expressed in retinol equivalents (RE) which equalled the amount of retinol + 0.167 (β-carotene) in μg/110 g fresh weight of root crop (Olson 1984).

2.18 Thiamin

The method of determining the thiamin content of root crops followed Bradbury and Singh (1986b) which consisted of using fresh (4 g) or dry (1.5 g) root crop homogenised and heated at 100 °C in 0.1 *M* HCl for 1 hour, followed by centrifugation to remove insoluble material. After treatment with basic lead acetate, dilute sulfuric acid and centrifugation, the thiamin was oxidised to the fluorescent compound thiochrome in alkaline solution using potassium ferricyanide. The thiochrome was extracted with isobutanol and the fluorescence of the solution was measured in a Perkin Elmer Model 512 fluorescence spectrometer in the excitation mode, with excitation wavelength 370 nm and emission wavelength 445 nm (Bradbury and Singh 1986b).

2.19 Riboflavin

About 4 g fresh or 1.5 g dry root crop was homogenised in acetate buffer at pH 4.3 and then heated at 100 °C for 1 hour. After centrifugation, the supernatant solution was oxidised with potassium permanganate, the excess permanganate was removed by hydrogen peroxide and the fluorescence of the riboflavin was measured as in section 2.18, with an excitation wavelength of 440 nm and an emission wavelength of 530 nm. The fluorescence of the sample was compared with that obtained after spiking the sample with a known amount of an authentic sample of riboflavin (Bradbury and Singh 1986b).

2.20 Nicotinic Acid

About 5 g fresh or 2 g dry root crop was homogenised in 0.5 M H_2SO_4 followed by heating at 100 °C for 1 hour. The pH was adjusted to 4.5 with sodium hydroxide and the solution was filtered. Ammonium sulfate was added followed by cyanogen bromide and sulfanilic acid which produced the coloured compound glutaconic dialdehyde. The colour intensity at 440 nm from the sample and the blank was compared with that from an authentic sample of nicotinic acid taken through the same treatment (Bradbury and Singh 1986b).

In the body, tryptophan is converted to nicotinic acid with variable efficiency and a factor of 60 is considered to be a useful approximation. The tables in Chapter 3 therefore contain an entry for potential nicotinic acid which equals tryptophan/60, which is added to the nicotinic acid content to give 'nicotinic acid equivalents' (total nicotinic acid).

2.21 Vitamin C (Ascorbic Acid + Dehydroascorbic Acid)

Fresh material (5 g) was homogenised in aqueous HPO_3 at room temperature and the extract was filtered. It was again filtered through an Acrodisc filter and run on an HPLC column (Waters, μ-Bondapak-NH_2 cartridge for a Z-module). The mobile phase was a (30:70) mixture of aqueous 0.005 M KH_2PO_4, adjusted to pH 4.6 with dilute HCl, and acetonitrile. The dehydroascorbic acid peak that eluted first was monitored at 210 nm and the peak due to ascorbic acid at 254 nm using a dual wavelength UV detector and dual-pen recorder. The area of each peak was quantitated against standard solutions of ascorbic acid and dehydroascorbic acid (Bradbury and Singh 1986a). The total vitamin C content equals the sum of the amounts of ascorbic acid and dehydroascorbic acid (Jaffe 1984).

2.22 Amino Acid Analysis

Amino acid analyses were carried out in duplicate on 25-mg samples of dry root crop using an LKB 3201 amino acid analyser (Bradbury et al. 1985b). Cystine was destroyed on acid hydrolysis in the presence of a large amount of starch and hence was determined in a separate analysis after oxidation to cysteic acid (Moore 1963). Tryptophan was also destroyed during the normal acid hydrolysis of proteins and was determined separately after hydrolysis in base. No corrections were made for losses of other amino acids by decomposition during acid hydrolysis. The amount of nitrogen present in each of the amino acids recorded was calculated and summed and compared with the total amount of nitrogen loaded on the column.

For tryptophan analysis a powdered sample of root crop dried at 40 °C was weighed into a hydrolysis tube. Sample weight was 1–2 g depending on the nitrogen content. Recrystallised barium hydroxide (2–3 g) was added followed by 10–20 ml distilled water. After thorough mixing, the tube was sealed in vacuo and heated at 110 °C for 16 hours. The tube was opened and the solution filtered through a glass frit. The filtrate was neutralised with H_2SO_4 to pH ~4 and made up to 50 ml. The precipitate of $BaSO_4$ was allowed to settle and about 10 ml of the supernatant was filtered through an Acrodisc filter in readiness for loading on the column.

A short (14 cm long, 1 cm internal diameter) jacketed column of spherical beads of Dowex 50 resin was prepared in citrate buffer (9.8 g sodium citrate dihydrate in 500 ml, pH adjusted to 4.25). The sample solution (1 ml) was loaded on the column,

heated at 50 °C and was eluted with citrate buffer at pH 5.4 (82.3 g sodium citrate dihydrate, 4.8 ml Brij 35, pH adjusted to 5.4 with HCl and diluted to 4 l). A large overlapping band of acidic and neutral amino acids was eluted followed by a separate peak identified as tryptophan by spiking the sample with an authentic sample of tryptophan prior to hydrolysis with barium hydroxide (Hugli and Moore 1972). The column was regenerated in the usual way by pumping through dilute NaOH solution, followed by citrate buffer at pH 4.25. The amount of tryptophan in the sample was determined by comparing the area under the tryptophan peak with that obtained by running on the same day 1 ml of a standard solution containing 100 nmol tryptophan/ml. Control experiments showed that the recovery of tryptophan obtained by addition of tryptophan to a root crop sample prior to alkaline hydrolysis was about 90%. This method, although slow, was much more reliable than the colorimetric method for tryptophan which utilised p(dimethylamino) benzaldehyde (Piombo and Lozano 1980), which we had used previously (Bradbury et al. 1985b).

An essential amino acid is one that cannot be produced by the human body and hence must be obtained in the diet. The amino acid score is defined as the percentage of an essential amino acid determined in the sample as compared with that of a certain pattern of requirement. The pattern used here is that proposed for a preschool child aged 2–5 years (table 38 of FAO/WHO/UNU1985) which gives the following values for the essential amino acids (in mg amino acid/g N in sample): histidine 119, isoleucine 175, leucine 413, lysine 363, methionine + cystine 156, phenylalanine + tyrosine 394, threonine 213, tryptophan 69 and valine 219. For any particular amino acid analysis, the calculated lowest amino acid score is called the chemical score and the amino acid that gives the lowest score is the first limiting amino acid.

It should be noted that the above values used for calculation of amino acid scores are different from those given in a previous FAO publication (FAO/WHO 1973). Thus earlier amino acid scores reported in the literature have (if necessary) been recalculated using the newest values reported above. The differences between the older and the new patterns of requirement are as follows: (1) histidine was not formerly but is now included as an essential amino acid; and (2) the new values for essential amino acids given above are smaller than the older ones (FAO/WHO 1973) except for lysine, phenylalanine + tyrosine and tryptophan which are larger. This has had the effect of decreasing the amino acid scores of the latter essential amino acids and of lysine in particular, which using the new values now becomes the first limiting amino acid in nearly all cases.

2.23 Organic Acids, Calcium Oxalate and Free Calcium

The powdered root crop sample (1 g), dried at 40 °C, was mixed with either 25 ml of distilled water or 25 ml of 0.25 *M* H_2SO_4 and 1 ml of internal standard (10 g of glutaric acid in 100 ml of water) was added. The mixture, in a glass-stoppered test tube, was heated in a water bath at 100 °C for 10 min, cooled and made up to 100 ml in a standard flask. A small volume of the solution was filtered and the filtered solution was again clarified by passage through an Acrodisc filter before injection into the HPLC. Separation was by a 300 × 7.8-mm ion-exclusion column (HPX-87H) using 0.0125 *M* H_2SO_4 eluent, flow rate 0.5 ml/min and a UV detector at 214 nm. Calibration of the system was obtained by a standard mixture which contained 20 mg of each of sodium oxalate, malic acid, sodium citrate, succinic acid and 80 mg of glutaric acid made up to 100 ml with 0.0125 *M* H_2SO_4. Known quantities of oxalic acid added to the original sample were recovered with 98% yield (Holloway et al. 1988). Retention times of oxalate, citrate, malate, succinate and glutarate were 9.8, 10.5, 12.5, 15.6 and

19.4 min, respectively, using 0.0125 M H_2SO_4, which was required to separate oxalate from a large unidentified peak which preceded it and originated from the sample preparation. Acid of lower concentration (0.004 M H_2SO_4) gave better separation of oxalate and citrate, but in this case the oxalate peak was obscured by the large unidentified peak already mentioned (Holloway et al. 1988).

The extraction with boiling water followed by cooling, dissolved water-soluble oxalates (potassium, sodium and ammonium oxalates and oxalic acid). Wills et al. (1983) used water for extraction of taro, and Picha (1985a) used 80% ethanol for extraction of sweet potato. It is doubtful whether 80% ethanol would extract sodium and potassium oxalates (see Appendix Table A.11). Extraction with hot dilute sulfuric acid dissolved water-soluble oxalates and calcium oxalate and hence gave a value for total oxalates. The amount of calcium oxalate (mg/100 g fresh weight) was therefore calculated from the difference between total oxalate (mg/100 g fresh weight) and water-soluble oxalate (mg/100 g fresh weight) by the equation

$$\text{calcium oxalate} = (\text{total oxalate-soluble oxalate})\ 128/88. \quad (4)$$

The results obtained for citrate, malate and succinate were the same, within experimental error, from the water extraction method and the sulfuric acid extraction method, and hence the results were averaged.

The total amount of calcium in the sample was obtained by atomic absorption and/or by ICP analyses (sections 2.15 and 2.16). Thus, the calcium not combined as calcium oxalate, the so-called free calcium (in mg/100 g fresh weight) may be calculated from the difference between the total calcium (in mg/100 g fresh weight) and the calcium oxalate (CaOx) by the equation

$$\text{free Ca} = \text{total Ca} - (40\ \text{CaOx}/128). \quad (5)$$

The amount of free calcium represents the calcium present in the root crop that is definitely available for human nutrition, whereas the calcium present as insoluble calcium oxalate may not be digestible (see section 5.3.1).

2.24 Trypsin Inhibitor Assay

A known weight of fresh root crop (10–40 g) or of the 40 °C dried sample was placed in a 100 ml measuring cylinder and buffer (485g Tris, 1.47g $CaCl_2 2H_2O$ dissolved in water, pH adjusted to 8.10 with HCl and made up to 1 l) added to make a total volume of 50 ml. The solution was homogenised using a Polytron for about 1 min, allowed to settle for 5 min and then centrifuged. The supernatant solution which contained trypsin inhibitor was then used to inhibit the rate of attack of the synthetic substrate p-tosyl-L-arginine methyl ester HCl (TAME, Sigma Chemical Co.) by trypsin (Sigma Chemical Co.) (Hammer 1987).

A solution of trypsin (1.00 mg/ml in 10^{-3} M HCl) was prepared. At least four 5-ml Tris buffer solutions were prepared, each of which contained different amounts (including zero) of the supernatant solution. Trypsin solution (0.050 ml) was added to each 5-ml solution which was mixed and allowed to stand for 10 min at 30 °C. An aliquot (0.100 ml) was taken from each of these solutions and added with stirring to 3 ml of TAME solution (0.001 M TAME dissolved in Tris buffer at pH 8.10) in a quartz cuvette. The cuvette was preincubated at 30.0 °C for 10 min and positioned in the carousel of a Varian Cary 219 spectrophotometer. The absorbance at 247 nm was measured for 5 min and there was always a linear dependence of absorbance on time. Control experiments using supernatant solutions, but in the absence of added trypsin, gave, as expected, no change in absorbance with time.

The residual tryptic activity of each trypsin incubated solution was obtained using a modification of the general formula for specific activity (in U/mg) (Bergmeyer et al. 1974) as follows:

$$U/mg = V\Delta A/\epsilon dvc\Delta t \qquad (6)$$

where U/mg is the turnover of TAME in μmol/min/mg trypsin, V is the assay volume (3.10 ml), ϵ is the extinction coefficient of the TAME hydrolysis product at 247 nm (0.540 $cm^2/\mu mol$; Hammer 1987), d is the path length of the cell (1 cm), v is the volume of trypsin incubated solution added to the cuvette (0.100 ml), c is the concentration of trypsin in the incubated solution (9.9×10^{-3} mg/ml) and ΔA is the change in absorbance at 247 nm in the time Δt (in min). For this assay the source and weight of trypsin was always the same at 0.050 mg, hence substitution in equation (6) gives (Hammer 1987)

$$U\ (\mu mol\ TAME/min)\ for\ this\ assay = 290\ \Delta A/\Delta t. \qquad (7)$$

A graph of the values (U) of the residual trypsin activity for each sample against the corresponding volumes of trypsin inhibitor supernatant solutions gave a straight line from zero inhibition (trypsin inhibitor supernatant solutions gave a straight line from zero inhibition (trypsin activity was 15.0 U) to > 50% inhibition. Zero inhibition that corresponded to a trypsin incubated solution containing no supernatant solution gave a tryptic activity of 15.0 ± 0.5 U(300 U/mg trypsin). We define a trypsin inhibitor unit (TIU) as the amount of inhibitor required to cause 50% inhibition of the trypsin activity present (viz. 15.0 U) using the conditions of the present assay. The volume of the supernatant solution containing 1 TIU was read off the graph and this was related back to the original weight of fresh root crop, hence the number of trypsin inhibitor units per gram of fresh root crop (TIU/g) was calculated (Bradbury et al. 1984a; Hammer 1987).

2.24.1 Diffusion Inhibitor Assay

The method of Gatehouse and Gatehouse (1979) was adapted by Hammer (1987) for the rapid, routine determination of trypsin inhibitor concentrations in solutions prepared from root crop samples.

2.25 Chymotrypsin Inhibitor Assay

The method used here was similar to that for trypsin inhibitor. The root crop sample was homogenised in buffer (4.85g Tris, 7.35g $CaCl_2 2H_2O$ dissolved in distilled water, pH adjusted to 7.82 by addition of HCl and made up to 500 ml with distilled water) and centrifuged as described for trypsin inhibitor in section 2.24. The supernatant solution which contained chymotrypsin inhibitor was used to inhibit the attack of the synthetic substrate N-benzoyl-L-tyrosine ethyl ester (BTEE, Sigma Chemical Co.) by α-chymotrypsin (Sigma Chemical Co., type II) (Hammer 1987).

A standard solution of α-chymotrypsin (1.00 mg/ml in 0.001 M HCl) was prepared. At least four 5-ml Tris buffer (pH 7.82) solutions were prepared, each containing different amounts (including zero) of the supernatant solution. Chymotrypsin solution (0.100 ml) was added to each 5 ml solution with mixing and incubation for 10 min at 25 °C. An aliquot (0.10 ml) of each of these incubated solutions was added with stirring to a quartz cuvette containing 2.9 ml of solution (1.4 ml of 0.001 M BTEE in 50% methanol: water (w/w) mixed with 1.5 ml of Tris buffer at pH 7.82). The cuvette was preincubated at 25 °C and placed in the carousel of the spectrometer. The absorbance at 256 nm was measured for 5 min and changed linearly

with time. Control experiments using supernatant solutions from all root crops studied, but in the absence of added chymotrypsin, gave no change in absorbance with time.

The residual chymotryptic activity of each chymotrypsin incubated solution was obtained using equation (6) in which $V = 3$ ml, ϵ is the extinction coefficient of the BTEE hydrolysis product N-benzoyl tyrosine at 256 nm (0.964 $cm^2/\mu mol$; Hammer 1987), d is 1.00 cm, v is 0.100 ml and c is 1.96×10^{-2} mg/ml. The same sample of chymotrypsin was used for all assays and the weight of chymotrypsin was always 0.100 mg and substitution in equation (6) gave

$$\text{U } (\mu\text{mol BTEE/min}) \text{ for this assay} = 159\Delta A/\Delta t. \quad (8)$$

As with trypsin a graph of the volumes (U) of residual chymotryptic activity for each sample against the corresponding volumes of chymotrypsin inhibitor supernatant solutions gave a straight line from zero inhibition (chymotryptic activity was 4.9 U) to >50% inhibition. A chymotrypsin inhibitor unit (CIU) was defined as the amount of inhibitor required to 50% inhibit 4.9 U of chymotryptic activity under the conditions of assay used here. The volume of supernatant solution required to 50% inhibit the chymotrypsin was read off the graph and was related back to the original weight of fresh root crop. The concentration of chymotrypsin inhibitor (in CIU/g) was then determined for the fresh root crop (Bradbury et al. 1985b; Hammer 1987).

2.26 Cyanide Analysis in Cassava

The method in outline consisted of extraction of the cyanide (both free and bound as linamarin) from cassava using aqueous phosphoric acid, the enzymatic hydrolysis of the linamarin using linamarase and the colorimetric determination of total cyanide. Free cyanide was determined in a separate experiment on the same sample, without the use of linamarase (Cooke 1978; Rao and Hahn 1984).

About 50 g of fresh peeled cassava (cut in sections across the tuber to avoid sampling problems, section 3.9), or cassava stored in the deep freeze at -20 °C, was blended with 160 ml of 0.1 *M* phosphoric acid. The acid solution was filtered through a GF/A glass filter paper; in some cases it was necessary to centrifuge the solution to remove solid material. The total volume of this stock solution was noted.

In order to determine total cyanide, 0.1 ml of the stock solution was added to 0.40 ml of 0.1 *M* phosphate buffer at pH 7 and 0.10 ml of linamarase solution was added. The linamarase solution was prepared by dissolving 50 EU of linamarase (BDH) in 20 ml of 0.1 *M* phosphate buffer at pH 6.0. After mixing, the solution was stoppered and incubated at 30–35 °C for 45 min. To determine free cyanide, the same procedure was followed but with no addition of linamarase. Sodium hydroxide solution (0.6 ml of 0.2 *M*) was added to stop the reaction followed by 6.8 ml 0.1 *M* phosphate buffer at pH 5.2 and 0.4 ml of chloramine-T (0.5 g/100 ml H_2O). The solution was mixed and cooled in ice for 5 min and 1.6 ml of pyridine reagent added. (The pyridine reagent consisted of 40 mg bispyrazolone (BDH) dissolved in 40 ml of pyridine to which was added a filtered solution of 1 g of 3-methyl-l-phenyl-5-pyrazolone (BDH) in 200 ml of water.) The solution was stoppered and allowed to stand for 60–130 min at room temperature to develop the colour, and the absorbance was measured at 620 nm. All analyses were made in duplicate. A check of the method was carried out using an authentic sample of linamarin, obtained from Calbiochem Laboratories. Also blank checks were made with no cassava sample present and both with and without linamarase.

A stock solution of 125 mg KCN (AR) was prepared in 500 ml of 0.2 *M* NaOH. Four working solutions were prepared fresh each day by quantitative dilution of up to

50 times of the stock solution to give a sixfold range of concentration. Aliquots (0.6 ml) of these solutions were taken through the same procedure for colour development as that given above and the absorbance of the solutions determined at 620 nm. A linear graph of absorbance vs concentration of cyanide was obtained from which the free and total cyanide concentrations of the cassava samples were determined.

Chapter 3. Chemical Composition of Root Crops

In this chapter, the chemical composition of the root crops and edible leaves is discussed, including current and earlier data, and the results are discussed. Detailed analyses have been made of the popular cultivars across several countries for most root crops. Since such data would undoubtedly be useful for those persons (e.g. agriculturalists and plant breeders) who may need to compare different cultivars within a particular country, we have included this detailed information in the Appendix tables. The root crops are considered separately (sweet potato, aroids (taros), yams and cassava), followed by a comparison of the composition of the various root crops. A final short section deals with the variability of composition of nutrients between tubers and corms.

3.1 Sweet Potato

The results given in Table 3.1 summarise the data of earlier workers on tubers and edible leaves and also our work on tubers. There are various sets of data that are not included, because they refer to one or only several analyses rather than a whole range of different analyses. Thus, Heywood and Nakikus (1982) summarised earlier Papua New Guinea results on moisture, energy and protein, Li (1982) gave protein results for 300 samples, and Purcell et al. (1972, 1978) gave protein and amino acid analyses for US sweet potato. Analyses for sugar (Tamate and Bradbury 1985; Picha 1985b; Truong et al. 1986), organic acids (Picha 1985a; Holloway et al. 1988), carotenoids (Martin 1983; Bushway 1986; Singh and Bradbury 1987) in sweet potato tubers and for Ca, Fe and Zn content of sweet potato greens (Pace et al. 1985b) have been reported.

When comparing the tuber results in Table 3.1 with those of the present study, it should be noted that the mean values reported (Table 3.2) were obtained from 164 samples from five South Pacific countries. Analyses for minerals other than Ca and Fe, vitamins and amino acids were from a more limited number of samples. The moisture, energy and protein values show considerable variability across the results of different workers. In much of the earlier work carbohydrate was obtained by difference, and fibre was expressed as crude fibre rather than as dietary fibre. Yellow sweet potato gave a higher value for sugar and for vitamin A (Paul and Southgate 1979) due to the β-carotene present which confers the colour, whereas the white sweet potato normally used in the South Pacific has only a small amount of vitamin A and a lower sugar content. There is good agreement amongst different workers in the results for the other vitamins. The results for minerals show reasonable agreement among different workers, except for sodium and zinc which are variable.

Table 3.1. Chemical composition of sweet potato tubers and edible leaves from present work (Table 3.2) and literature sources.

	Tubers								Edible leaves			
	Present Work, Table 3.2	*Paul and Southgate (1979)* [a]	*Wenkam (1983)*	*South Pacific Comm. (1983)*	*Oomen et al. (1961)*	*Ohtsuka et al. (1984)*	*Goodbody (1984)*	*Peters (1957)*	*Wenkam (1983)*	*Villareal et al. (1979)*	*Peters (1957)*	*Oomen and Grubben (1978)*
Number of samples and country	164 samples, 5 South Pac. countries		1 sample, Hawaii		4 results, PNG	1 sample PNG	93 samples, Simbu, PNG	3 samples, Central America[b]	1 sample Hawaii	10 cvs Taiwan	2 samples, Central America[b]	
Moisture %	71.1	70.0	70.2	—	75.4	80.6	68.2	68.4	87.8	85.5	86.3	86.7
Energy (kJ/100g)	438	387	477	480	—	322	—	—	151	—	—	176
Protein %	1.43	1.2	1.6	1.5	1.19	1.1	1.0	1.03	4.0	2.81	3.99	3.2
Starch %	20.1	11.8	—	—	14.1	—	—	—	—	—	—	—
Sugar %	2.38	9.7	—	—	4.7	—	—	—	—	—	—	—
Carbohydrate % (diff.)	—	—	27	26	—	15.5	—	—	6.6	—	—	—
Dietary fibre %	1.64	2.5	—	—	—	—	—	—	—	—	—	—
Crude fibre %	—	—	0.8	—	0.95	1.1	1.5	0.85	1.2	1.9	1.6	1.6
Fat %	0.17	0.6	0.14	0.3	—	0.7	1.0	0.12	0.3	—	0.83	—
Ash %	0.74	—	1.1	—	0.79	1.1	—	0.93	1.3	1.7	1.24	—
Oxalate (mg/100g)[g]	89	—	—	—	—	—	—	—	—	370	—	—
Calcium oxalate (mg/100g)	32	—	—	—	—	—	—	—	—	—	—	—
Minerals (mg/100g)												
Calcium, Ca	29	22[c]	30	25	29	21	—	22	37	75	110	85
Phosphorus, P	51	47[c]	37	—	48	49	—	31	94	—	30	—
Magnesium, Mg	26	13[c]	12	—	27	20	—	—	62	—	—	—
Sodium, Na	52	19[c]	47	—	1	19	—	—	9	—	—	—
Potassium, K	260	320[c]	380	—	—	360	—	—	530	—	—	—
Sulfur, S	13	16[c]	—	—	—	—	—	—	—	—	—	—
Iron, Fe	0.49	0.7[c]	0.40	1.0	—	0.62	—	1.1	1.0	3.9	2.9	4.5
Copper, Cu	0.17	0.16[c]	—	—	—	0.15	—	—	—	—	—	—
Zinc, Zn	0.59	—	—	—	—	0.21	—	—	—	—	—	—
Manganese, Mn	0.11	—	—	—	—	0.25	—	—	—	—	—	—
Aluminium, Al	0.82	—	—	—	—	—	—	—	—	—	—	—
Boron, B	0.10	—	—	—	—	—	—	—	—	—	—	—
Vitamins (mg/100g)												
Vitamin A (ret. + β-car/6)	0.011	0.67	0.077	0.03 +	—	—	—	0.69	0.18	1.67	1.7	2.7

Thiamin	0.086	0.10	0.10	0.10	—	—	—	0.11	0.16	—	0.086	—
Riboflavin	0.031	0.06	0.028	0.04	—	—	—	0.70	0.37	0.35	0.26	—
Nicotinic acid	0.60	0.8	0.45	0.7	—	—	—	0.66	1.14	—	1.1	—
Pot. Nic. Acid = Trp/60	0.32	0.4	—	—	—	—	—	—	—	—	—	—
Vitamin C	24	25	15	30				34	11	41	58	20
Vitamin D	0	0										
Limiting Amino Acids and Score												
First	Lys 70[f]	—	—	—	54 S-contg	-	69 Lys					
Second	Leu 80[f]	—	—	—	56 Lys[d]		83 S-contg[e]	—	—	—	—	—
Trypsin Inhibitor (TIU/g)	13.4	—	—	—	—	—	—	—	—	—	—	—
Edible matter, prop. of wt. purchased	—	0.86	0.90	0.85	—	—	—	—	0.71	—	—	—

[a] Yellow sweet potato. Amount of other vitamins: vitamin E 4.0[c], vitamin B_6 0.22, vitamin B_{12} 0, folic acid 52, pantothenic acid 0.94.
[b] Munsell et al. 1949; 1950a, b; 1953.
[c] Results are estimates.
[d] Recalculated with new standards (FAO/WHO/UNU 1985).
[e] Mean of 15 Simbu cultivars. Recalculated (FAO/WHO/UNU 1985).
[f] Based on 33 analyses of PNG highland sweet potato (Bradbury et al. 1984a, 1985b), four analyses of Solomon Islands and of Tongan sweet potato (Appendix Table A.10) with new standards (FAO/WHO/UNU 1985).
[g] Results for other organic acids and free calcium are given in Appendix Table A.11.

Table 3.2. Summary of sweet potato data from Solomon Islands, Tonga, PNG Lowlands and Highlands, Western Samoa and Fiji.

Source of sweet potato	*Moisture %*	*Energy (kJ/100 g)*[a]	*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Total oxalate (mg/100 g)*	*Calcium oxalate (mg/100 g)*[b]	*Calcium (mg/100 g)*	*Iron (mg/100 g)*	*Trypsin inhibitor (TIU/g)*	*Chymo-trypsin inhibitor (CIU/g)*	*Sum of (a+b+c+d+e+f+g) %*
	a		*b*	*e*	*f*	*g*	*c*	*d*							
Solomon Islands Table A.1	72.2	416	1.28	17.7	3.21	2.62	0.17	0.73	97	38	35.6	0.47	25.4	0.99	97.9
Solomon Islands Table A.2	69.9	462	2.14	20.6	2.90	1.43	0.17	0.70	—	—	39.4	0.47	—	—	97.8
Tonga Table A.3	72.6	416	0.85	19.4	2.59	1.58	0.19	0.76	—	—	35.6	0.45	22.3	—	98.0
Laloki PNG Lowland Table A.4	71.5	438	1.70	20.3	2.63	1.20	0.10	0.83	—	—	27.0	0.51	—	—	98.3
Kuk PNG Highland Table A.5	72.8	414	1.30	19.5	1.92	1.53	0.21	0.79	—	—	12.8	0.38	3.5	zero	98.1
Western Samoa Table A.6	66.1	514	1.80	23.4	2.56	1.45	0.19	0.60	—	—	29.4	0.72	—	—	96.1
Fiji Table A.7	72.6	406	0.92	19.9	0.89	1.66	0.17	0.74	40	25	24.4	0.44	2.2	—	96.9
Grand Mean	71.1	438	1.43	20.1	2.38	1.64	0.17	0.74	—	—	29.2	0.49	13.4	—	97.6
SD	2.4	39	0.47	1.7	0.75	0.50	0.03	0.07	—	—	8.9	0.11	12.2	—	—

[a] Average value from the two methods of calculation, sections 2.12 and 2.13.
[b] See Table A.11.

The analytical data on sweet potato edible leaves are incomplete with gaps for starch, sugar, dietary fibre, some minerals and amino acids. Compared with tubers, the leaves contain much more moisture and hence much less energy, more protein, Mg, K, Fe, vitamin A, riboflavin and nicotinic acid. Edible green leaves are an important source of vitamins, protein and minerals (section 1.2.1).

The summary of results for sweet potato samples from five countries is given in Table 3.2, and the detailed results on a cultivar-by-cultivar basis for each country are given in Appendix Tables A.1 to A.7. The sum of all the major components in sweet potato tubers in Table 3.2 amounts to 97.6% which is within experimental error of 100% and is a check of the overall correctness of the data. The results for the different countries are generally similar but there are some differences of interest. The moisture content (inversely related to the energy content; section 2.13) is lowest in tubers from Western Samoa (grown under wet conditions) and highest in those from the PNG Highlands. However, it is often quite low for sweet potato from the PNG Highlands (Goodbody 1984; Bradbury et al. 1984a, 1985b). The basis of the variability of moisture content with environment is discussed in section 6.1.1. The results for Solomon Islands (Appendix Table A.2) and Tongan sweet potatoes (Appendix Table A.3) show significant differences between the moisture content of different cultivars.

There is a significant increase in the crude protein content of samples from Solomon Islands of the same cultivar from 1983 to 1984 (Table 3.2 and Appendix Tables A.1 and A.2). This may be due to the fact that the 1983 samples were planted at Tenaru, in an area cropped previously with sweet potato, and also because the rainfall was low during the growing period. The sugar content of sweet potato from Fiji and PNG Highlands is low compared with Solomon Islands and much lower than that of yellow sweet potato (Table 3.1). Analyses for each different sugar are given in Table 4.1 and also by Tamate and Bradbury (1985) and Bradbury et al. (1988a), and the large increase in maltose content due to cooking is noted. The calcium content of PNG Highlands sweet potato is also low compared with that of other samples in Table 3.2, possibly due to low calcium content in the soil. In a separate experiment at Kiburu (Southern Highland Province, PNG) sweet potatoes were grown in adjacent plots in the absence and presence of added gypsum ($CaSO_4$) at 500 kg/ha (Bradbury et al. 1985b). Results on a range of cultivars showed a very significant increase from 12.9 (SD 2.9) in absence of gypsum to 18.4 (SD 3.7) mg/100 g in the presence of gypsum (section 6.2.3). In this case, the calcium content of the tuber was shown to be related to the calcium content of the soil, as also shown below for the case of giant swamp taro. Bradbury et al. (1985b) found the trypsin inhibitor content of sweet potatoes varies, hence the large variability shown in Table 3.2. The amount of chymotrypsin inhibitor present was either very small or zero.

The detailed results for the various cultivars from each individual country are given in Appendix Tables A.1 to A.7. In general, the cultivars analysed are the ones commonly grown in that locality or country. The obvious exceptions to this rule are TIS 2498 analysed from Solomon Islands and Fiji and three TIS and two TIB cultivars in Appendix Table A.7 which were obtained from the International Institute of Tropical Agriculture (IITA), Nigeria. In general, the cultivars were grown on research stations, but two cultivars from Tonga (Appendix Table A.3) were obtained from farmers' fields. Fertilizer was generally not used, except for the Fijian cultivars in Appendix Table A.7.

Analyses (Appendix Table A.2) for moisture and for Dumas and Kjeldahl nitrogen (crude protein) results over 10 tubers of each of four cultivars showed: (1) good agreement between the different analytical methods indicating that inorganic nitrogen-containing compounds such as nitrate were absent from sweet potato; (2) the Kjeldahl method was more reproducible than the Dumas method; (3) that the variability in

protein content between different tubers of the same cultivar normally exceeded the variability of the analytical method; (4) that TIS 2498 was a significantly drier cultivar than either Three Months or 220 MK 10; and (5) that TIS 2498 had a significantly higher protein content than the local cultivar Santa Cruz.

Results in Appendix Table A.3 for Tonga sweet potato showed that: (1) Hawaii and Tongamai produced significantly drier (higher energy) tubers than Melefakahau; (2) Hawaii gave the highest protein content and Siale was by far the lowest; (3) Siale gave the highest sugar content and Halasika the lowest in the uncooked tuber (see Chapter 4 for effect of cooking); and (4) Hawaii had the highest calcium content and Halasika the lowest. All these differences were statistically significant. Similar differences were observed between cultivars in Appendix Tables A.4 to A.7. This showed that most of the major nutritional traits of the sweet potato tuber, viz. energy, protein, sugar and calcium content, were cultivar-dependent and hence should be subject to manipulation by selection and/or breeding.

The detailed results of mineral analyses of sweet potato from Solomon Islands and Tonga are given in Appendix Table A.8. Significant differences between mineral contents of Ca, P, Mg, Na, Fe, Cu, Mn, Al and B are noted from the two countries, which may result from differences in composition of the soils in which the tubers were grown. The only differences between the vitamin contents of sweet potatoes from PNG, Solomon Islands and Tonga is that there is significantly less nicotinic acid present in the cultivars from Tonga than in those from the other two countries (Appendix Table A.9).

The amino acid analyses of eight sweet potato cultivars from Solomon Islands and Tonga are given in Appendix Table A.10 and these will now be considered along with 33 analyses of cultivars from the Southern Highlands of PNG reported earlier (Bradbury et al. 1984a, 1985b). Recalculation of the amino acid scores using the new FAO/WHO/UNU (1985) values gave a mean chemical score for lysine and leucine of 83%. In Appendix Table A.10 the first limiting amino acid was lysine with a chemical score of 59% (Tonga) and 69% (Solomon Islands). When the results in that table were averaged with the previous recalculated results from PNG, lysine was the first limiting amino acid with a chemical score of 70 (SD 12), and leucine was the second limiting amino acid with a score of 80 (SD 5). Sulfur-containing amino acids, formerly considered to be limiting in many cases (Oomen et al. 1961; Bradbury et al. 1984a), were now found not to be limiting because of: (1) the decreased value used in the calculation of the new score (FAO/WHO/UNU 1985) as compared with the previous value (section 2.22); and (2) likely errors in determination of cystine in earlier work (Oomen et al. 1961).

The content of oxalate and other organic acid anions and calcium oxalate is given in Appendix Table A.11. The amounts of water soluble oxalate and of calcium oxalate were small. Even if calcium oxalate is not utilised in the human body, there is still a reasonable amount of free calcium available for human nutrition (Holloway et al. 1988). The content of organic acid anions was quite variable between different tubers of the same cultivar and also between different cultivars; in some samples succinate was not present.

3.2 Taro

3.2.1 Taro, *C. esculenta* var. *esculenta*

The chemical composition of taro corms and of taro edible leaves is given in Table 3.3. Because of the more limited interest in *Colocasia* taro as compared with sweet potato, few additional analyses have been made on taro except for work on acridity

(see section 5.4). In general, there is reasonable agreement between the results of different workers. However, recent results for crude protein obtained in the South Pacific region by ourselves and Wills et al. (1983) show that the earlier values including the South Pacific Commission value of 2.0 should be revised downwards. The value for sodium for the Pacific region is low; our value for Fe is lower than that obtained by others, and our value for Zn is higher than that obtained by Ohtsuka et al. (1984) and Wills et al. (1983). The latter reported variable results for zinc content, with low levels in taro corms from two districts with zinc-deficient soils. The vitamin A content of taro corms is very low; our value for thiamin is lower than that of others and our value for vitamin C is higher than others, by an amount which approximately equals the dehydroascorbic acid content of taro. The latter was not determined by earlier methods, but should be included as part of the total vitamin C (Bradbury and Singh 1986a).

The edible leaves of taro fulfil nutritional expectations of green leaves as discussed in Chapter 1, viz. they are a good source of protein and of all the vitamins listed, but especially of vitamin A, riboflavin and vitamin C. The energy content, which is low compared with the corm, has been considerably overstated by earlier workers, because of its calculation using a carbohydrate content obtained by difference. We obtained a very low starch content and hence low energy content, and a large amount of dietary fibre. The high fat content compared with the corm is largely due to the wax present on the surface of the shiny leaf, which may not be digested by humans.

In Table 3.4, the data are summarised for analyses of taro corms from three successive plantings of the same cultivars in Fiji, and from single plantings in Western Samoa and Solomon Islands. Taro suckers (see section 1.1.2) and edible leaves were also analysed. In Table 3.4 the moisture content of the first planting (grown in the wet season) is significantly greater than that of the second planting, grown in the dry season. The high moisture content for Solomon Islands taro is largely due to the inclusion of results from 10 lines bred for their resistance to *Phytophthora*, which the taste panel in Solomon Islands described as spongy (see Appendix Table A.17). The calcium content of Solomon Islands taro in Table 3.4 is the highest and its iron content is the lowest.

Appendix Table A.14 gives the data for taro over three successive plantings of popular (e.g. Samoa, Toakula, Hawaii) and breeding lines (e.g. Samoa green, Samoa hybrid) from Fiji. The results for the four cultivars that are common to the three plantings, viz. Samoa green, Samoa, Toakula and Tausala ni Samoa, have been analysed and show a higher protein in the first crop, except for Toakula which is similar at all harvests. There is an interesting parallel to be drawn with sweet potato from the Southern Highlands of PNG. Bradbury et al. (1985b) found that for 10 common cultivars grown over five different environments there was much more variability in protein content across the environment, compared with these results. The range of protein content of taro in our results is about fourfold, which is considerably less than the ninefold range of protein content observed among cultivars of sweet potato (section 7.1). The sugar content in the first harvest is significantly greater than in the second and third harvests. Analyses of individual sugars present in taro are given in section 4.4.

Results from two popular taro cultivars obtained from the Suva market are given in Appendix Table A.15. The composition of Samoa and Toakula cultivars is similar to the results obtained for the three harvests of the same cultivars obtained from the research station (Appendix Table A.14) grown with added fertilizer. This shows that data on chemical composition obtained from local popular cultivars, grown with added fertilizer in the research station, may be validly used for nutritional purposes in the present study and probably also with other root crops.

Table 3.3. Taro *(C. esculenta)*, chemical composition of corms and leaves from present work and literature sources.

	Taro corms							*Taro edible leaves*			
	Present work Tables 3.4, A.19–A.21 and A.23	*Wenkam (1983)*	*South Pac. Comm. (1983)*	*Standal (1983)*	*Ohtsuka et al. (1984)*	*Wills et al. (1983)*	*Peters (1957)*	*Present work Tables 3.4, A.19, A.22 and A.23*	*Wenkam (1983)*	*Standal (1983)*	*Parkinson (1984 a, b)*
Number of samples and country	71 Samples from 3 countries			India and Philippines	3 Samples PNG	36 Samples from 22 cv PNG Highlands	2 Samples[a] from Central America	10 Fijian cv		India and Philippines	Food comp. tables FAO 1972[b]
Moisture %	69.1	72.4	—	75	66.6	66.8	66.8	85.4	87.5	81.0	81.4
Energy (kJ/100 g)	480	439	470	376	545	509	—	114	151	260	255
Protein %	1.12	1.48	2.0	2.7	1.8	1.2	2.25	4.2	5.0	4.2	4.0
Starch %	24.5	—	—	—	—	26.2	—	0.07	—	—	—
Sugar %	1.01	—	—	—	—	1.0	—	0.92	—	—	—
Carbohydrate % (diff.)	—	24.8	26	20	29.9	—	—	—	4.8	9.5	11.9 incl. fibre
Dietary fibre %	1.46	—	—	—	—	3.8	—	5.03	—	—	—
Crude fibre %	—	0.61	—	0.7	0.7	—	0.6	—	2.0	3.3	—
Fat %	0.10	0.11	—	0.15	0.1	0.3	0.27	0.61	0.74	1.7	—
Ash %	0.87	1.20	—	0.8	1.0	1.0	1.1	1.58	1.9	2	—
Total oxalate[d] (mg/100 g)	65	—	—	—	—	36	—	426	—	—	—
Calcium oxalate (mg/100 g)	43	—	—	—	—	—	—	400	—	—	—
Free calcium	10	—	—	—	—	—	—	24	—	—	—
Minerals (mg/100 g)											
Ca	32	23	25	38	17	19	13	182	107	250	162
P	70	69	—	64–140	50	—	46	61	60	80	69
Mg	115	20	—	—	45	28	—	90	35	—	—
Na	1.8	12	—	8	0.7	1	—	7.9	2	11	—
K	448	323	—	530	348	340	—	487	437	1240	963
S	8.5	—	—	—	—	—	—	24	—	—	—
Fe	0.48	1.7	1.0	0.8–1.7	1.5	1.1	0.77	0.62	2.3	—	1.0
Cu	0.20	—	—	—	0.24	—	—	0.15	—	—	—
Zn	3.6	—	—	—	1.2	1.7	—	0.66	—	—	—
Mn	0.34	—	—	—	0.47	—	—	4.5	—	—	—
Al	0.39	—	—	—	—	—	—	1.81	—	—	—
B	0.09	—	—	—	—	—	—	0.36	—	—	—

Vitamins (mg/100 g)											
Vitamin A											
(ret. + β-car./6)	0.007	0	—	0.02	—	—	0	—	0.50	7.3	5.5
Thiamin	0.032	0.14	0.10	0.09	—	—	0.13	—	0.14	0.16	0.13
Riboflavin	0.025	0.02	0.03	0.03	—	—	0.036	—	0.31	0.3	0.34
Nicotinic acid	0.760	0.44	1.0	0.6	—	—	1.38	—	1.0	1.6	1.5
Pot. Nic. Acid =											
Trp/60	0.19	—	—	—	—	—	—	1.0	—	—	—
Vitamin C	15	4	5	0–10	—	—	6.9	—	37	12–140	63
Vitamin D	0	—	—	—	—	—	—	—	—	—	—
Limiting Amino Acids and Score											
First	Lys 66	—	—	Lys 66[c]	—	—	—	Leu 57	—	—	—
Second	Thr 94	—	—	His 92	—	—	—	Lys 62	—	—	—
Trypsin inhibitor (TIU/g)	13.6	—	—	—	—	—	—	zero	—	—	—
Edible matter, prop. of wt. purchased	—	0.86	0.80	0.81	—	—	—	—	0.65	0.55	—

[a] Munsell et al. (1950c).
[b] Folic acid content of edible leaves is 0.163 mg/100 g.
[c] These results were recalculated using the new pattern of requirement (section 2.22).
[d] For other organic acids see Table A.23.

Table 3.4. Summary of composition of corms, suckers and edible leaves of taro *Colocasia* from Fiji, Western Samoa and Solomon Islands.

Part of plant and source	*Moisture* %	*Energy (kJ/100 g)*[a]	*Protein* %	*Starch* %	*Sugar* %	*Dietary fibre* %	*Fat* %	*Ash* %	*Total oxalate (mg/100 g)*	*Calcium oxalate (mg/100 g)*[b]	*Calcium* (mg/100 g)	*Iron* (mg/100 g)	*Trypsin inhibitor* (TIU/g)	*Sum of (a+b+c+* d+e+f+g)
	a		*b*	*e*	*f*	*g*	*c*	*d*						
Corms, Fiji Table A.14 (first)	70.1	473	1.39	22.4	1.86	1.75	0.12	1.01	—	—	29.0	0.69	2.7[c]	98.6
Corms, Fiji Table A.14 (second)	62.9	575	0.95	29.8	0.98	1.23	0.11	0.75	—	—	21.0	0.73	—	96.2
Corms, Fiji Table A.14 (third)	65.2	536	0.98	28.0	0.73	1.26	0.09	0.87	65	37	23.0	0.51	—	96.6
Corms, Fiji Table A.15	65.9	543	1.21	28.8	1.21	1.45	0.08	0.74	—	—	15.4	0.80	—	99.4
Corms, Western Samoa Table A.16	71.4	444	0.89	23.9	0.40	1.23	0.07	0.75	—	—	25.8	0.38	8.8	98.6
Corms, Solomon Islands Table A.17	78.6	308	1.22	14.0	1.11	1.83	0.10	0.98	—	—	60.8	0.29	5.1	97.0
Mean of corms	69.1	480	1.12	24.5	1.01	1.46	0.10	0.87	—	—	31.7	0.52	13.6	97.7
Suckers, Fiji Table A.14	67.6	499	0.81	26.2	0.64	1.27	0.11	0.80	60	—	13.6	0.36	12.0	97.0
Leaves, Fiji Table A.18	85.4	110	4.20	0.07	0.92	5.03	0.61	1.58	426	400	182	0.62	zero	97.1

[a] Average value from the two methods of calculation, sections 2.12 and 2.13.
[b] See Appendix Table A.23 for organic acids.
[c] Negligible amounts of chymotrypsin inhibitor were present from three different cultivars tested.

The results for common cultivars of taro from Western Samoa are given in Appendix Table A.16. The cultivar Manua is called Samoa in Fiji, and Niue is named Tausala ni Samoa in Fiji (Wilson, J. E., pers. comm.). A comparison of the compositions of these pairs of cultivars in Appendix Tables A.16 and A.14 shows that there are no significant differences between the chemical compositions as a result of change of country (except for trypsin inhibitor which is absent from Manua but present in Samoa). There are significant differences, however, between the chemical compositions of different cultivars grown in the same environment. Thus, there are significant differences in protein, sugar, ash, Ca and Fe contents between different cultivars in Appendix Table A.16 and highly significant differences in Ca and Fe contents between different cultivars in Table A.14 (second harvest).

The composition of taro corms from four common cultivars and 10 *Phytophthora*-resistant lines from Solomon Islands is given in Appendix Table A.17. The mean composition of the four popular cultivars is similar to that of the common cultivars from Fiji and Western Samoa. The ten breeding lines have high moisture and hence low starch and energy contents. They also have a low Fe content and some have a high Ca content.

The composition of taro leaves given in Appendix Table A.18 includes cultivars with edible leaves and some that are not eaten. The results in this table show that there is no difference in the nutrient content between the edible and nonedible leaves, which is not surprising because the reason that the latter are not eaten is that they are acrid (see section 5.4). Another point of interest is the considerable difference between the values of E_a, calculated from the amount of protein, fat, starch and sugar present using the Atwater factors and E_b calculated from the moisture content (sections 2.12 and 2.13). In this case the value of E_b is incorrect, although it is in reasonable agreement with Standal (1983) and Parkinson (1984a) (see Table 3.3), which are also probably incorrect. The value of E_b is much too high because the calculation on which it is based is only valid for foods which contain small amounts of dietary fibre (Bradbury 1986; section 2.2.9). The high values obtained by Standal (1983) and Parkinson (1984a) were due to the fact that carbohydrate content was obtained by difference and hence the 5% of dietary fibre was incorrectly included as available carbohydrate.

The mineral content of taro corms and leaves is given in Appendix Table A.19. Taro corms contain only about one-thirtieth the amount of sodium as sweet potato, and about 60% more potassium, and on average more zinc, although the zinc content is variable as also observed by Wills et al. (1983). Taro leaves contain much more Ca, Na, S, Mn, Al and B, and much less Zn, than corms. The vitamin content of taro corms is given in Appendix Table A.20. The only difference observed between countries is that the riboflavin content of Solomon Islands taro is significantly less than for taro from Fiji.

In Appendix Table A.21 the results of 11 amino acid analyses on taro samples from Fiji are recorded and four analyses on samples from Western Samoa. Although there are considerable variations between the results of different cultivars, lysine is the first limiting amino acid with an average chemical score of 66 and threonine is the second limiting amino acid with a mean score of 94, significantly greater ($P < 0.01$) than the value of 66. The value of lysine agrees with results (recalculated using the FAO/WHO/UNU (1985) values) reported by Standal (1983) in which lysine was limiting with a chemical score of 66, but not with those of Hussain et al. (1984) for taro cormels from Bangladesh, for which tryptophan was limiting with a chemical score of 29, and S-containing amino acids and lysine gave scores of 56 and 83 respectively. For taro leaves the results in Appendix Table A.22 show that leucine is

limiting with a chemical score of 57, which is, however, not significantly different from the value of 62% for lysine.

In Appendix Table A.23 results for organic acid anions including oxalate are given. There is only a small amount of soluble oxalate present in corms, which agrees well with the average value of 36 obtained by Wills et al. (1983) who extracted 36 samples of taro corms with water. The calcium oxalate content of corms is also small and the amount of free calcium present would be adequate for human nutrition. Taro leaves contain three times more soluble oxalate and ten times more calcium oxalate than corms. However, there is still a reasonable amount of free calcium remaining. There were variable amounts of organic acid anions present, and in some samples succinate was not present. Taro suckers contained no appreciable amounts of malate, citrate or succinate. The significance of these results with regard to the acridity of aroids is discussed in section 5.4.

3.2.2 Taro, *X. sagittifolium*

The amount of data on taro *Xanthosoma* is much less than that for taro *Colocasia*. For example, our corm analyses for starch, sugar and dietary fibre, for most of the minerals, and for amino acids appear to be the first reported. The results show that, in general, taro *Xanthosoma* has a very similar composition to that of taro *Colocasia*. The calcium content of our cultivars is lower than the results obtained by other workers (Table 3.5). The difference could perhaps be explained if previous workers had analysed the mother corm (which is not eaten in the South Pacific; section 1.1.3) rather than the cormels which we analysed. One might expect that the cormels would contain less Ca than the corms, as this was found with taro *Colocasia* (Table 3.4). Some of the previously reported values for vitamin A, thiamin, riboflavin and vitamin C were obviously too high by one or two orders of magnitude. There was only a very small amount of trypsin inhibitor present in the three cultivars studied. There are appreciable differences between the results of *Xanthosoma* from Tonga and PNG, particularly for calcium and sugar, which are normally subject to wide variations with environment, and to a lesser extent in dietary fibre, ash and iron. Results of leaf analyses by other workers are incomplete but show high values for protein, fibre, calcium oxalate and vitamins.

The analyses on nine corms of each of three cultivars from Tonga are given in Appendix Table A.25. The results show that there are significant differences in moisture and starch content between Maheleuli and Futuna and in iron content between Futuna and Tea. The amount of soluble oxalate and of calcium oxalate is quite small. The amount of calcium available for utilisation in the body is virtually zero (see section 5.3.2). The total oxalate content is much less than that found for three different West Indian species of *Xanthosoma* (de Escabi and Cedeno-Maldonado 1985). The amounts of malate, citrate and succinate respectively in Appendix Table A.25 increase in that order. The amino acid analyses in Appendix Table A.27 show that for every analysis lysine is the first limiting amino acid with an average chemical score of 57. Leucine is the second limiting amino acid with a score of 81.

3.3 Giant Taro, *A. macrorrhiza*

The results of our work on 37 samples of 12 popular cultivars from Western Samoa and Tonga are compared with those of other workers in Table 3.6. Results that were not formerly available are given for starch, dietary fibre, various minerals, amino acids, trypsin and chymotrypsin inhibitors and organic acids (Table 3.7). In general, our results show higher protein and vitamin C contents than previously observed, and

Table 3.5. Taro (*X. sagittifolium*) composition of edible corms and leaves from present work and literature sources.

	Corms						*Edible leaves*
	Present work						*Chowdhury and Hussain (1979)*
	Table A.25	*Table A.26*	*Mean*	*Parkinson (1984a)*	*Standal (1982)*	*Onwueme (1978)*	
Number of samples and country	*27 samples 3 cv (from Tonga)*	*10 samples 2 cv (from PNG)*		*Food Comp. Table, East Asia, FAO 1972*		*Range of values*	*2 samples*
Moisture %	68.1	66.0	67.1	75.4	65	70–77	83.9
Energy (kJ/100 g)	496	545	521	393	560	—	—
Protein %	1.44	1.66	1.55	2.2	2.0	1.3–3.7	3.5
Starch %	25.7	29.4	27.6	—	—	—	—
Sugar %	0.57	0.27	0.42	—	—	—	—
Carbohydrate % (diff.)	—	—	—	21.0 incl. crude fibre	31.0	17–26	—
Dietary fibre %	1.15	0.82	0.99	—	—	—	—
Crude fibre %	—	—	—	—	—	0.6–1.9	3.02
Fat %	0.12	0.10	0.11	—	0.3	0.2–0.4	1.66
Ash %	1.12	0.96	1.04	—	—	0.6–1.3	1.90
Total oxalate[a] (mg/100 g)	60	—	—	—	—	—	680
Calcium oxalate (mg/100 g)	23	—	—	—	—	—	—
Minerals (mg/100 g)							
Ca	5.9	11.1	8.5	34	20	—	283
P	53	—	53	62	—	—	61
Mg	27	—	27	—	—	—	51
Na	6.6	—	6.6	—	—	—	8.7
K	530	—	530	448	—	—	—
S	7.9	—	7.9	—	—	—	—
Fe	0.47	0.33	0.40	1.2	1.0	—	5.9
Cu	0.19	—	0.19	—	—	—	—
Zn	0.52	—	0.52	—	—	—	—
Mn	0.17	—	0.17	—	—	—	—
Al	0.53	—	0.53	—	—	—	—
B	0.09	—	0.09	—	—	—	—
Vitamins (mg/100 g)							
Vitamin A (ret. + β-car./6)	0.005	—	0.005	tr	0	0.33	4.5
Thiamin	0.024	—	0.024	0.12	1.1	0.06	—
Riboflavin	0.032	—	0.032	0.04	0.03	0.2	—
Nicotinic acid	0.80	—	0.80	1.0	0.5	1	—
Pot. Nic. acid = Trp/60	0.33	—	0.33	—	—	—	—
Vitamin C	13.6	—	13.6	8	10	96	65
Limiting amino acids and score							
First	Lysine 57	—	Lys 57	—	—	—	—
Second	Leucine 81	—	Leu 81	—	—	—	—
Trypsin inhibitor (TIU/g)	0.3	—	0.3	—	—	—	—
Edible matter, prop. of wt. purchased	—	—	—		0.77–0.86	—	—

[a]Results for other organic acids and free calcium given in Table A.25.

the absence of β-carotene (vitamin A) confirms previous results. We have observed the presence of a large amount of an enzyme inhibitor which inhibits both trypsin and chymotrypsin (section 5.2). Digestion of the protein of uncooked giant taro by animals would be prevented by this inhibitor, but since it is inactivated (denatured) by prolonged cooking, it is not deleterious for human nutrition.

A comparison between the mean compositions of the two sets of giant taro samples obtained in successive years from Western Samoa and for the three cultivars from Tonga, showed very few differences (Table 3.7). The only significant difference

Table 3.6. Giant taro (*A. macrorrhiza*) composition of corms and leaves from present work and literature sources.

	Corms				*Edible leaves*
	Present work Table 3.7	*South Pacific Comm. (1983)*	*Sakai (1983)*	*Parkinson (1984a,b)*	*(Sakai 1983)*
Number of samples and country	*37 samples from W. Samoa and Tonga*	*Source is Murai et al. (1958) Hawaii*	*Various sources*		*Bangladesh*
Moisture %	70.3	81.3	63–87	84	—
Energy (kJ/100 g)	449	290	290–600	255	—
Protein %	2.15	0.6	0.6–3.3	0.6	0.3–4.3
Starch %	21.5	—	—	—	—
Sugar %	0.96	—	0.5	—	—
Carbohydrate % (diff.)	—	16.9	3–20	14.8	4–6
Dietary fibre %	1.85	—	—	—	—
Crude fibre %	—	—	1–3	—	1–2.7
Fat %	0.10	0.1	0.02–0.9	—	0.1–0.9
Ash %	0.92	—	0.8–1.4	—	0.8–1.4
Total oxalate (mg/100 g)	38	—	150	—	—
Minerals (mg/100 g)					
Ca	38	152	46–160	30	57–235
P	44	45	45–72	50	25–99
Mg	52	—	—	—	—
Na	30	—	—	—	—
K	267	—	—	—	—
S	11.9	—	—	—	—
Fe	0.83	0.5	0.5–1.0	1.0	0.6–3.8
Cu	0.07	—	—	—	—
Zn	1.51	—	—	—	—
Mn	0.62	—	—	—	—
Al	0.36	—	—	—	—
B	0.10	—	—	—	—
Vitamins (mg/100 g)					
Vitamin A (ret. + β-car./6)	0	—	tr	0	0.15–2.2
Thiamin	0.021	0.10	0.01–0.1	0.05	0.01–0.09
Riboflavin	0.018	0.02	0.01–0.03	—	0.01–0.34
Nicotinic acid	0.48	0.4	0.4	—	—
Pot. Nic. acid = Trp/60	0.46	—	—	—	—
Vitamin C	17.0	tr	0–7	5	5
Limiting amino acids and score					
First	Lysine 64	—	—	—	—
Second	His 91, Ileu 93	—	—	—	—
Trypsin inhibitor (TIU/g)	269	—	—	—	—
Chymotrypsin inhibitor (CIU/g)	57	—	—	—	—
Edible matter, prop. of wt. purchased	—	—	0.82	—	—

Table 3.7. Composition of giant taro (*A. macrorrhiza*) corms from Western Samoa and Tonga.[a]

		W. Samoa Table A.28	*W. Samoa Table A.29*	*Tonga Table A.30*	*Mean*	*SD*
Number of samples		*6 cv*	*6 cv, duplicate corms*	*3 cv, duplicate corms*		
Moisture %	a	70.6	70.4	69.9	70.3	0.4
Energy (kJ/100 g)		442	452	452	449	6
Protein %	b	2.39	2.72	1.35	2.15	0.72
Starch %	e	20.5	21.4	22.5	21.5	1.0
Sugar %	f	1.24	1.01	0.64	0.96	0.30
Dietary fibre %	g	1.79	1.43	2.34	1.85	0.46
Fat %	c	0.13	0.08	0.09	0.10	0.03
Ash %	d	0.91	0.71	1.13	0.92	0.21
Calcium (mg/100 g)		28.1	26.3[a]	60.3	38.2	19.1
Iron (mg/100 g)		0.88	0.83[a]	0.79	0.83	0.05
Vitamins (mg/100 g)						
Vitamin A (ret + β-car./6)		—	0	—	0	—
Thiamin		—	0.021 (0.010)	—	0.021	0.01
Riboflavin		—	0.018 (0.008)	—	0.018	0.008
Nicotinic acid		—	0.48 (0.26)	—	0.48	0.26
Ascorbic acid (AA)		—	7.7 (1.7)	7.8 (4.2)	7.7	2.5
Dehydroascorbic acid (DAA)		—	9.3 (2.4)	9.2 (2.1)	9.3	1.9
Total vitamin C (AA + DAA)		—	17.0 (3.1)	17.0 (5.2)	17.0	3.4
Organic acid anions (mg/100 g)						
Total oxalate		30	45	—	38	11
Soluble oxalate		—	17	—	17	8
Calcium oxalate		—	37	—	37	28
Free calcium		—	15	—	15	10
Malate		370	320	—	345	35
Citrate		318	238	—	278	57
Succinate		290	450	—	370	113
Trypsin inhibitor (TIU/g)		339	198	—	269	100
Chymotrypsin inhibitor (CIU/g)		57	—	—	57	22
Sum of (a + b + c + d + e + f + g)		97.6	97.8	98.0	—	—

[a]Results for other minerals given in Table A.29.

was the higher calcium content of the giant taro from Tonga. The amounts of soluble oxalate and calcium oxalate were both fairly small and similar to taro and sweet potato, although a large gradient of calcium oxalate concentration across the corm is observed for giant taro (see section 5.3.2). The free calcium content, which measures calcium available for digestion, also appears to be adequate. The malate, citrate and succinate contents were about ten times that of oxalate and were variable from one sample to another.

The detailed results in Appendix Tables A.28 to A.30 allow four comparisons. The first is to compare results obtained from two different years of harvest (1984 and 1985, Appendix Tables A.28 and A.29) using the same cultivars (Niukini, Toga, Sega and Fui) in both seasons and also in some cases, comparing cultivars of similar age. No significant differences were found across different years for Niukini, Fui and Toga but Sega showed differences between moisture, dietary fibe and oxalate. Since the corms under comparison were grown at different sites and this in itself is a cause of variability, it may perhaps be concluded that the differences across years of harvest

were quite small. The second comparison that can be made from the results in Appendix Table A.29 is between corms of similar age grown in a farmer's field and those grown in a research station. With Niukini no differences were observed but with Toga the research station corms contained less moisture and more dietary fibre, sugar and iron than those of similar age from the farmer's field. Since giant taro may be harvested at any time up to an age of 4–6 years (section 1.1.4) a third comparison may be based on the age of the corm. The only data available are with Toga in Appendix Table A.29. It was concluded that no significant differences existed between 3-year and 1.2-year corms of Toga. This tentative conclusion requires confirmation over a range of cultivars (see section 6.6). The fourth comparison possible is between different cultivars grown under the same conditions. In Appendix Table A.30, results show that the cultivar Tuu contains more moisture and less protein, starch, sugar and iron than the other cultivars. The most popular cultivar Tea contains less dietary fibre and Fohenga more sugar than the other cultivars. Thus, certain cultivars of giant taro are nutritionally superior compared with others.

The amino acid analyses of four cultivars of giant taro from Western Samoa are given in Appendix Table A.31. The results show lysine to be the first limiting amino acid with a chemical score of 64, similar to that of taro *Colocasia and Xanthosoma*.

3.4 Giant Swamp Taro, *C. chamissonis*

A comparison between the mean of our analyses on 10 different common cultivars from Kiribati and Pohnpei, grown in farmers' fields and pits, and the results of other workers, is made in Table 3.8. Our results show a higher moisture content and hence lower energy than those of other workers. Also our results for protein, calcium, riboflavin and nicotinic acid are at the low end of the values of other workers. The

Table 3.8. Composition of corms and leaves of giant swamp taro (*C. chamissonis*) from present work and literature sources.

	Corms						*Edible leaves*
	Present work						
	Table A.33	*Tables A.34, A.35*	*Mean*	*South Pacific Comm. (1983)*	*Sakai (1983)*	*Parkinson (1984a)*	*(Sakai 1983)*
Number of samples and country	*17 analyses 5 cv Kiribati*	*10 analyses 5 cv Pohnpei*			*Philippines, Micronesia*	*Source Murai et al. (1983)*	*Philippines*
Moisture %	79.4	71.9	75.4	—	60–70	—	89
Energy (kJ/100 g)	290	406	348	510	493–648	548	146
Protein %	0.57	0.45	0.51	0.8	0.5–1.9	0.9	3.2
Starch %	13.5	20.1	16.8	—	—	—	—
Sugar %	1.06	1.00	1.03	—	0.5	—	—
Carbohydrate % (diff.)	—	—	—	29.2 incl. fib.	23–33	31.0	4
Dietary fibre %	2.36	3.19	2.78	—	—	—	—
Crude fibre %	—	—	—	—	1.6	—	1.4
Fat %	0.14	0.17	0.16	0.2	0.1–0.5	—	0.6
Ash %	0.74	0.57	0.67	—	0.9–1.9	—	1.6

Table 3.8. (Continued)

	Corms						*Edible leaves*
	Present work						
	Table A.33	*Tables A.34, A.35*	*Mean*	*South Pacific Comm. (1983)*	*Sakai (1983)*	*Parkinson (1984a)*	*(Sakai 1983)*
Number of samples and country	*17 analyses 5 cv Kiribati*	*10 analyses 5 cv Pohnpei*			*Philippines, Micronesia*	*Source Murai et al. (1983)*	*Philippines*
Minerals (mg/100 g)							
Ca	219	145	182	577	158–600	334	—
P	14	17	16	—	28–79	56	—
Mg	25	18	21	—	—	—	—
Na	100	44	72	—	—	—	—
K	53	81	67	—	—	—	—
S	4.0	2.6	3.3	—	—	—	—
Fe	0.46	0.75	0.61	1.3	0.9–1.4	1.2	—
Cu	0.09	0.14	0.11	—	—	—	—
Zn	1.02	3.5	2.3	—	—	—	—
Mn	0.22	1.16	0.69	—	—	—	—
Al	1.30	1.42	1.36	—	—	—	—
B	0.08	0.10	0.09	—	—	—	—
Vitamins (mg/100 g)							
Vitamin A (ret. + β-car./6)	0.005	—	0.005	—	0–1.3	0	—
Thiamin	0.025	—	0.025	0.027	0.01–0.06	0.05	—
Riboflavin	0.019	—	0.019	0.11	0.04–0.11	0.07	—
Nicotinic acid	0.46	—	0.46	1.2	0.6–1.2	0.88	—
Pot. Nic. acid = Trp/60	0.08	0.06	0.07	—	—	—	—
Vitamin C	15.7	—	15.7	—	—	0–2	—
Vitamin D	0	—	0	—	—	—	—
Organic acid anions (mg/100 g)							
Total oxalate	300	297	299	—	—	—	—
	(218)	(179)					
Soluble oxalate	—	45	45	—	—	—	—
		(39)					
Calcium oxalate	—	399	399	—	—	—	—
		(62)					
Free calcium	—	10	10	—	—	—	—
		(27)					
Malate	170	106	138	—	—	—	—
	(170)	(42)					
Citrate	50	121	86	—	—	—	—
	(60)	(52)					
Succinate	450	140	295	—	—	—	—
	(670)	(80)					
Limiting amino acids and score							
First	Lys 70, Trp 70	—	Lys 70, Trp 70	—	—	—	—
Second	Leu 87	—	Leu 87	—	—	—	—
Trypsin inhibitor (TIU/g)	2.5	—	2.5	—	—	—	—
Edible matter, prop. of wt. purchased	—	—	—	—	0.68	—	—

total oxalate content is much larger than for other root crops due to the large amount of calcium oxalate, about ten times that present in other root crops (see section 5.3.2). The soluble oxalate content is fairly low and there is a small amount of free calcium present, although the results for this are variable (see Appendix Table A.34). There is only a small amount of trypsin inhibitor present, which is destroyed on cooking (section 5.2.5).

The major difference between the results from Kiribati and Pohnpei is the increased moisture content of the Kiribati samples, which has resulted in decreased energy and starch content as compared with those from Pohnpei. Also, the Kiribati corms have increased calcium and sodium, and decreased iron, zinc and succinate levels compared with Pohnpei corms.

Giant swamp taro may be planted and harvested at any time (see section 1.1.6), hence a comparison of the composition of corms was possible over different ages. As shown in Appendix Table A.33, there was a general increase of calcium with age for three cultivars, usually matched by an increase of oxalate which is discussed in section 6.5. A study across two different environments, the mainland and the atoll of Pohnpei (Appendix Tables A.34 and A35), showed many changes in nutrient composition of corms of the same cultivar especially for oxalate, calcium and other minerals (see section 6.5).

The amino acid analyses given in Appendix Table A.36 show that lysine and tryptophan are the first limiting amino acids with a chemical score of 70. The result for lysine is similar to that obtained for the other edible aroids.

3.5 Elephant Foot Yam, *A. campanulatus*

This is an edible aroid of minor importance in the South Pacific, hence we have less data than for the other aroids. A comparison is given in Table 3.9 between our results and those of other workers. The present work extends the range of analyses previously available. Our cultivar contained larger amounts of Ca, P, Mg and less Fe than that of other workers. Elephant foot yam is generally high in moisture, total calcium, calcium oxalate and total oxalate, like giant swamp taro, but contains a much larger amount of protein and K than giant swamp taro.

3.6 Yam, *Dioscorea spp.*

3.6.1 Yam, *D. alata*

The chemical composition of yam (*D. alata*) from PNG, Solomon Islands and Western Samoa obtained in the present study is given in Table 3.10, together with earlier data from seven other sources. In general, our moisture content is at the high end of those results previously reported, and hence our energy value is at the low end. Our values for vitamin A and vitamin C are generally high and for calcium at the low end compared with other workers. The protein content of *D. alata* from Solomon Islands is high and the iron content of *D. alata* from PNG is low. The latter may perhaps be related to low iron content of soils in the East Sepik Province of PNG (Quin, M. F., pers. comm.). The results of *D. alata* for the three different countries given in Appendix Tables A.37–A.39 are quite consistent. The most notable difference is the high protein content of the Solomon Islands yams in Appendix Table A.38, with one value of 4.19%. These results and those for crude protein of PNG *D. alata* were checked by both the Kjeldahl and Dumas methods. In our experience this large protein content has been exceeded only by giant taro (4.87% protein). Non-protein, non-amino acid nitrogen in *D. alata* was estimated at about 10% by Splittstoesser (1976). It

Table 3.9. Composition of corms of elephant foot yam (*A. campanulatus*) from present work and literature sources.

	Present work[a]	*Sakai (1983)*	*Chowdhury and Hussain (1979)*	*Parkinson (1984a)*
Number of samples and country	*7 samples of one cv from PNG*	*Mean of cv from Bangladesh and Philippines*	*One sample from Bangladesh*	*From FAO (1972)*
Moisture %	77.8 (6.3)	75	89.4	78.5
Energy (kJ/100 g) E_a	324	374	—	339
E_b	347	—	—	—
Protein %	2.24 (0.41)	3.1	0.56	2.0
Starch %	16.6 (0.8)	—	6.72	—
Sugar %	0.14 (0.07)	—	—	—
Carbohydrate % (diff.)	—	20	—	18.4
Dietary fibre %	1.45 (0.40)	—	—	—
Crude fibre %	—	0.74	—	—
Fat %	0.06 (0.01)	0.74	0.14	—
Ash %	1.36 (0.24)	0.94	0.31	—
Minerals (mg/100 g)				
Ca	127 (8)	53	26	38
P	67 (9)	37	32	38
Mg	47 (7)	—	22	—
Na	4.1 (0.6)	—	5.8	—
K	622 (81)	—	—	416
S	11.8 (4.4)	—	—	—
Fe	0.51 (0.21)	1.0	1.17	2.4
Cu	0.18 (0.09)	—	—	—
Zn	1.05 (0.11)	—	—	—
Mn	0.31 (0.12)	—	—	—
Al	0.41 (0.20)	—	—	—
B	0.17 (0.03)	—	—	—
Organic acid anions (mg/100 g)				
Total oxalate	288 (134)	—	—	—
Soluble oxalate	25 (6)	—	—	—
Calcium oxalate[b]	382 (186)	—	—	—
Free calcium[b]	8 (5)	—	—	—
Malate	513 (68)	—	—	—
Citrate	256 (81)	—	—	—
Succinate	339 (140)	—	—	—
Vitamins (mg/100 g)				
Vitamin A (ret. + β-car./6)	—	0.15	—	0
Thiamin	—	0.05	—	0.06
Riboflavin	—	0.07	—	0.02
Nicotinic acid	—	0.7	—	1.7
Vitamin C	—	1.5	—	6
Edible matter, prop. of wt. purchased	—	0.89	—	—

[a]Seven corms of one cultivar obtained from Port Moresby area of PNG, October 1986.
[b]Calculated as shown in section 2.23.

is interesting that the cultivar A172 with the highest protein content also gave by far the best yield, yet was not considered to be among the best in Solomon Islands, perhaps because of poor resistance to anthracnose diesease (Appendix Table A. 38). There is also significantly more dietary fibre present in cultivars from Solomon Islands than in those from PNG. The trypsin inhibitor content of *D. alata* is very small (see

Table 3.10. Composition of yam (*D. alata*) tubers from PNG, Solomon Islands and Western Samoa (present work) and from literature sources.

	Present work				*Coursey (1983b)*	*Onwueme (1978)*	*Parkinson (1984a,b)*	*Ologhobo (1985)*	*Ohtsuka et al. (1984)*	*Peters (1957)*	*Egbe and Treche (1984)*
	Table A.37	*Table A.38*	*Table A.39*	*Mean*							
Number of samples and country	6 cv, PNG	8 cv, Solomon Islands	2 cv, 10 samples Western Samoa				Source, FAO (1972)	1 sample Nigeria	1 sample PNG	Source, Intengan et al. (1954)	23 samples Cameroons
Moisture %	78.6	75.5	77.7	77.3	65–73	70	71.8	76.2	75.5	76.6	75.6
Energy (kJ/100 g)	311	381	348	347	—	—	452	—	398	—	—
Protein %	1.35	3.05	2.04	2.15	1.1–2.8	1.1–2.8	2.0	1.42	1.4	1.7	2.01
Starch %	15.9	17.5	16.7	16.7	—	28	—	—	—	—	17.7
Sugar %	0.77	1.39	0.94	1.03	—	0.5	—	—	—	—	—
Carbohydrate % (diff.)	—	—	—	—	22–29	—	25.1	—	21.3	—	—
Dietary fibre %	1.19	2.36	2.10	1.88	—	—	—	—	—	—	1.20
Crude fibre %	—	—	—	—	0.6–1.4	0.6–1.4	—	0.21	0.7	0.6	—
Fat %	0.07	0.10	0.06	0.08	0.03–0.27	0.1–0.8	—	0.57	0.1	0.05	0.06
Ash %	0.75	0.88	0.79	0.81	0.7–2.0	0.7–2.1	—	0.93	1.1	0.86	—
Minerals (mg/100 g)											
Ca	5.7	8.3	10.7	8.2	—	—	22	4.4	14	10	7.1
P	32	—	44	38	—	—	39	4.8	58	41	28
Mg	17.7	—	16.2	17.0	—	—	—	11	17.8	—	6.6
Na	2.34	—	4.3	3.3	—	—	—	108	6.2	—	2.2
K	312	—	324	318	—	—	294	224	451	—	329
S	9.8	—	14.4	12.1	—	—	—	—	—	—	—
Fe	0.14	0.51	1.15	0.60	—	—	1.0	0.88	0.44	0.62	1.05
Cu	0.14	—	0.16	0.15	—	—	—	0.055	0.147	—	0.21
Zn	0.36	—	0.41	0.39	—	—	—	0.24	0.49	—	0.36
Mn	0.02	—	0.05	0.04	—	—	—	0.64	0.019	—	—
Al	0.10	—	1.18	0.64	—	—	—	—	—	—	—
B	0.09	—	0.08	0.09	—	—	—	—	—	—	—
Vitamins (mg/100 g)											
Vitamin A (ret. + β-car./6)	0.018[a]	—	—	0.018	—	—	0	—	—	0	—
Thiamin	0.031	0.063	—	0.047	—	0.09	0.10	—	—	0.09	—
Riboflavin	0.024	0.036	—	0.030	—	0.03	0.04	—	—	0.033	—
Nicotinic acid	0.355	0.408	—	0.382	—	—	0.07	—	—	0.47	—
Pot. Nic. acid = Trp/60	0.28	0.60	—	0.44	—	—	—	—	—	—	—
Ascorbic acid (AA)	—	10.0	—	10.0	—	—	—	—	—	—	—
Dehydroascorbic acid (DAA)	—	17.6	—	17.6	—	—	—	—	—	—	—
Total vitamin C (AA + DAA)	—	27.6	—	27.6	5–8.2	5–8	—	—	—	2	—

Limiting amino acids and scores											
First	Lys 71	Lys 71	—	Lys 71	—	—	—	—	—	—	—
Second	Leu 91	Leu 91	—	Leu 91	—	—	—	—	—	—	—
Organic acid anions (mg/100 g)											
Total oxalate (Ox)	15.0	20.2	—	17.6	—	—	—	—	—	—	—
Malate	123	87	—	105	—	—	—	—	—	—	—
Citrate	127	157	—	142	—	—	—	—	—	—	—
Succinate	0	0	—	0	—	—	—	—	—	—	—
Mole ratio Ox/Ca	1.45	1.02	—	1.24	—	—	—	—	—	—	—
Trypsin inhibitor (TIU/g)	0.56	—	—	0.56	—	—	—	—	—	—	—
Edible matter, prop. of wt. purchased	—	—	—	—	—	—	—	—	—	0.90	—

[a]No vitamin D present (Singh and Bradbury 1988).

Appendix Table A.37) compared with sweet potato and the aroids. The oxalate content is small compared with other root crops and the mole ratio of oxalate to calcium is variable as shown in Appendix Tables A.37 and A.38.

The amino acid analyses, given in detail for eight cultivars in Appendix Table A.40, showed lysine to be the first limiting amino acid with an average chemical score of 71, followed by leucine with a score of 91. This result is in good agreement with the results of three analyses reported by Francis et al. (1975), which we have recalculated using the new FAO/WHO/UNU (1985) scoring system. The recalculated results show lysine to be the first limiting amino acid with a mean chemical score of 64 and leucine second with a score of 86. However, the recalculated results of Splittstoesser et al. (1973a) indicated that the S-containing amino acids (cystine + methionine) were limiting with a chemical score of 64 followed by lysine with 81. The bulk of evidence supports the conclusion that lysine is the first limiting amino acid.

3.6.2 Yam, *D. esculenta*

The results we obtained on tubers from Solomon Islands and PNG are compared with those of other workers in Table 3.11. Inspection shows a number of gaps in the data of earlier workers which have been filled by our work. In many cases, comparisons can be made and these show few differences, except that our protein values are high or at the high end of the range of earlier workers. Our values for nicotinic acid are much lower than the only other value obtained by Intengan et al. (1954). The calcium content of *D. esculenta*, like *D. alata* and other yams, is low and so is the total oxalate content, compared with other root crops. Trypsin and chymotrypsin inhibitors were not present in any of the samples studied.

In Appendix Table A.41 mean results from 3–4 tubers taken from two plants are compared for cultivars NGP4, GUP5 and GUP4. Significant differences are found between the calcium contents of the tubers of the two plants of the same cultivar for all three cultivars, and NGP4 shows a difference in sugar content between the two plants. A similar study of the protein and amino acid content of sweet potato tubers showed quite substantial differences between tubers from different plants of the same cultivar (Bradbury et al. 1985b).

The effect of environment on tuber composition was investigated using five *D. esculenta* cultivars planted in two sites in Solomon Islands at Dodo Creek, Guadalcanal, and Dala, Malaita. The results are given in Appendix Table A.42 and are discussed in section 6.3. A second environment trial using local cultivars of *D. esculenta* in three sites in PNG is reported in Appendix Table A.43. There were no significant differences between mean values of nutrient content across the three sites. There were, however, significant differences in the calcium content of cultivars Glame and Mart. The variability of calcium content between different plants of the same cultivar (see above) and across three different environments of the same cultivar shows the sensitivity of this nutrient, probably towards differences in soil calcium levels (see section 6.3).

The iron content of all *D. esculenta* cultivars from East Sepik (Appendix Table A.43) was low compared with the Solomon Islands results (Appendix Table A.41) and those of other workers (Table 3.11). This is consistent with the low iron content of *D. alata* from East Sepik compared with *D. alata* from Solomon Islands, and the suggestion by Quin (pers. comm.) that the iron content of East Sepik soils may be low (section 3.7.1).

The amino acid analyses in Appendix Table A.44 and the calculated amino acid scores show that lysine is the first limiting amino acid with an average chemical score of 59 over four different cultivars. This agrees well with a chemical score for lysine of 69 (Coursey 1983b) and 62 (Splittstoesser et al. 1973 a, b), after recalculation with the

new FAO/WHO/UNU (1985) values. Our data show a large gap between lysine (first limiting) and three other amino acids, whereas the results of Coursey (1983 b) and Splittstoesser et al. (1973a) place the S-containing amino acids as the second limiting amino acids with scores of 84 and 64 respectively.

Analyses of five tubers of each of eight cultivars from Solomon Islands reported in table 13 of ACIAR/ANU Program (1986) showed that there were highly significant differences between the moisture, energy and protein contents of different cultivars. Thus it should be possible to select *D. esculenta* cultivars for high protein and high energy.

3.6.3 Yam, *D. nummularia*

The results obtained for *D. nummularia* from Western Samoa and Vanuatu are given in Table 3.12. We have been unable to find any other analyses on *D. nummularia* The results show no appreciable differences between the mean values obtained from the two countries. However, there are significant differences between different cultivars in moisture, energy, protein, starch, sugar and dietary fibre as shown in Appendix Tables A.45 and A.46. This indicates the possibility of selection of *D. nummularia* cultivars for improved nutrient content. As with *D. alata* and *D. esculenta* species, lysine was found to be the first limiting amino acid with a chemical score of 64 (see Appendix Table A.47). There is still a lack of information on the vitamins present in *D. nummularia*.

3.6.4 Yam, *D. bulbifera*

The results for *D. bulbifera* are summarised in Table 3.12, and detailed results for each cultivar are given in Appendix Table A.48. Comparison of results for Vanuatu *D. bulbifera* with those from Africa shows that the Vanuatu samples have much more moisture, and hence less energy, and starch than the others. Appreciable differences are also observed in Mg, Fe and Cu contents which probably reflects differences in the amounts of these minerals in the soils. There is a lack of information on the vitamin content of *D. bulbifera*. The very low chemical score of 36 for the S-containing amino acids obtained by Splittstoesser et al. (1973a) must be considered doubtful, when compared with amino acid analyses on other yam species which gave chemical scores of 52–80.

3.6.5 Yam, *D. pentaphylla*

A comparison is made in Table 3.13 between our data on three cultivars from Vanuatu and old results from the Philippines and vitamin results from Hawaii. The yams analysed all have a high moisture content (see Appendix Table A.48) and hence a low energy and starch content like *D. bulbifera, D. trifida* and *D. alata*. The calcium content of the Vanuatu *D. pentaphylla* samples in Appendix Table A.48 is generally higher than for other species. There is no amino acid analysis information on this species.

3.6.6 Yam, *D. rotundata*

The present results and those of other workers in Table 3.13 show that *D. rotundata* has low moisture content and hence a high starch and energy content. There are some large differences between mineral analyses particularly for P, Na and Mn which may be due to errors of measurement techniques as well as differences in composition of soils in different countries. There are also differences between the first limiting amino acids recorded. Splittstoesser et al. (1973 a) found the S-containing amino acids limiting with a score of 60, but Francis et al. (1975) found lysine to be limiting with a chemical score of 82.

Table 3.11. Composition of yam (*D. esculenta*) tubers from PNG and Solomon Islands (present work) and from literature sources.

	Present work									
		Table A.42								
	Table A.41	Dodo Creek	Dala	Table A.43	Mean	Coursey (1983b)	Onwueme (1978)	Peters (1957)	Egbe and Treche (1984)[a]	Ologhobo (1985)
Number of samples and country	5 cv 26 samples Solomon Is.	5 cv 15 samples Solomon Is.	5 cv 13 samples Solomon Is.	10 cv 45 samples PNG		Coursey (1967)		Intengan et al. (1954) Philippines	12 cv West Africa	Single tuber, Nigeria
Moisture %	74.4	75.7	70.7	76.0	74.2	67–81	70–80	71.8	70.3	76
Energy (kJ/100 g)	395	383	470	374	406	—	—	—	—	482
Protein %	2.30	1.77	2.10	2.07	2.06	1.3–1.9	1.3–1.9	1.20	1.51	1.8
Starch %	19.4	18.0	22.2	17.7	19.3	—	25	—	20.9	—
Sugar %	0.78	—	—	0.32	0.55	—	0.6	—	—	—
Carbohydrate % (diff)	—	—	—	—	—	17–25	—	—	—	—
Dietary fibre %	1.09	1.15	1.40	0.94	1.15	—	—	—	—	—
Crude fibre %	—	—	—	—	—	0.18–1.51	0.2–1.5	0.5	0.77	0.21
Fat %	0.04	—	—	0.07	0.06	0.04–0.29	0.1–0.3	0.08	0.07	0.11
Ash %	0.90	—	—	0.74	0.82	0.5–1.24	0.5–1.2	0.84	—	0.64
Minerals (mg/100 g)[c]										
Ca	7.3	9.5	6.9	6.2	7.5	—	—	18.9	7.4	3.2
P	—	41	33	42	39	—	—	40.7	26.4	5.2
Mg	—	30	25	24	26	—	—	—	11.1	9.9
Na	—	3.7	3.5	2.1	3.1	—	—	—	1.16	108
K	—	393	175	341	303	—	—	—	374	218
S	—	18.4	16.0	13.9	16.1	—	—	—	—	—
Fe	0.91	0.77	1.03	0.28	0.75	—	—	0.48	0.89	1.4
Cu	—	0.14	0.21	0.17	0.17	—	—	—	0.34	0.05
Zn	—	0.43	0.48	0.46	0.46	—	—	—	0.63	0.32
Mn	—	0.08	0.58	0.06	0.24	—	—	—	—	0.32
Al	—	0.64	0.55	0.35	0.51	—	—	—	—	—
B	—	0.07	0.07	0.08	0.07	—	—	—	—	—
Vitamins (mg/100 g)										
Vitamin A (ret. + β-car./6)	—	—	—	0.017	0.017	—	—	—	—	—
Thiamin	—	0.044	—	0.045	0.045	—	0.08	0.084	—	—
Riboflavin	—	0.030	—	0.026	0.028	—	0.02	0.016	—	—
Nicotinic acid	—	0.450	—	0.378	0.41	—	—	1.07	—	—
Pot. Nic. Acid = Trp/60	—	0.66	—	—	0.66	—	—	—	—	—
Ascorbic acid (AA)	13.0[b]	—	—	—	13.0	—	—	—	—	—
Dehydroascorbic acid (DAA)	7.3[b]	—	—	—	7.3	—	—	—	—	—
Total vitamin C (AA + DAA)	20.3[b]	—	—	—	20.3	—	—	17	—	—

Limiting amino acid and scores										
First	Lys 59	—	—	—	Lys 59	—	—	—	—	—
Organic acid anions[d] (mg/100 g)										
Total oxalate (Ox)	8.5	—	—	16.9	12.7	—	—	—	—	—
Malate	102	—	—	64	83	—	—	—	—	—
Citrate	99	—	—	147	123	—	—	—	—	—
Succinate	0	—	—	0	0	—	—	—	—	—
Mole ratio Ox/Ca	0.53	—	—	1.24	0.89	—	—	—	—	—
Trypsin inhibitor (TIU/g)	0	—	—	—	0	—	—	—	—	—
Chymotrypsin inhibitor (CIU/g)	0	—	—	—	0	—	—	—	—	—
Edible matter (prop. of wt. purchased)	—	—	—	—	—	—	—	0.80	—	—

[a] Recalculated on wet basis. Results for Mg, Fe, Zn, Cu and Na were recorded as g/100 g, but we think they should have read mg/100 g.

[b] Vitamin C analyses made on five common cultivars received September 1985.

[c] Mineral analyses for Dodo Creek and Dala were on two cultivars NGP3 and Fanania from each site and a significant difference was found in results for K. For PNG all cultivars were analysed for Ca and Fe (Table A.43) and four cultivars (Mart (Saramandi), Glame and Kamart (Numango) and Biartgu (Mikau)) were analysed for other minerals.

[d] Organic acids were analysed for 4 cv from Solomon Islands and 5 cv from PNG.

Table 3.12. Composition of yam *(D. nummularia)* tubers from Western Samoa and Vanuatu and yam *(D. bulbifera)* from Vanuatu (present work) and data from literature sources.

	D. nummularia			*D. bulbifera*		
	Table A.45 and A.47	*Table A.46*	*Mean present work*	*Table A.48*	*Egbe and Treche (1984)*	*Coursey (1983b)*
Number of samples and country	2 cv, 10 samples Western Samoa	5 cv, 15 samples Vanuatu		4 cv, 12 samples Vanuatu	11 samples Cameroon	not known
Moisture %	71.4	70.6	71.9	81.7	71.2	63–67
Energy (kJ/100 g)	443	443	443	258	461	—
Protein %	1.88	2.19	2.04	1.94	1.78	1.1–1.5
Starch %	23.0	23.4	23.2	11.7	21.0	—
Sugar %	0.13	0.30	0.22	0.20	—	—
Carbohydrate % (diff.)	—	—	—	—	—	27–33
Dietary fibre %	1.33	2.34	1.84	1.42	1.01	—
Crude fibre %	—	—	—	—	—	0.72
Fat %	0.04	0.07	0.06	0.05	0.07	0.04
Ash %	0.92	0.97	0.95	0.69	—	1.1–1.5
Minerals (mg/100 g)						
Ca	7.8	5.1	6.5	8.4	6.6	—
P	—	40	40	27	37	—
Mg	—	20	20	19	7.1	—
Na	—	8.6	8.6	2.7	4.0	—
K	—	448	448	346	337	—
S	—	15	15	9.0	—	—
Fe	0.42	0.34	0.38	0.56	1.3	—
Cu	—	0.34	0.34	0.21	0.42	—
Zn	—	0.50	0.50	0.31	0.51	—
Mn	—	0.04	0.04	0.13	—	—
Al	—	0.29	0.29	0.49	—	—
B	—	0.05	0.05	0.10	—	—
Limiting amino acids + score						
First	Lys 64	—	Lys 64	—	S-contg 36[a]	—

[a] Splittstoesser et al. (1973a)

3.6.7 Yam, *D. trifida*

The data for *D. trifida* are probably less complete than that for any of the other yam species given. The samples analysed had a high moisture content and hence were low in starch and energy (Table 3.13). The other nutrients analysed were present at the levels found for other yam species. The first limiting amino acid may be S-containing (cystine + methionine), tryptophan or possibly lysine with a chemical score of about 58. No information is available on vitamins present in *D. trifida.*

3.7 Cassava, *M. esculenta*

The results of the present work on cassava tubers from Solomon Islands, Fiji and PNG, and that from literature sources on tubers and leaves, are given in Table 3.14. Since the production of cassava worldwide exceeds that of any other tropical root crop, it is surprising that the published data available to us are less complete than for

Table 3.13. Composition of yams *(D. pentaphylla, D. rotundata* and *D. trifida)* from Vanuatu (present work) and data from literature sources.

	D. pentaphylla		*D. rotundata*				*D. trifida*	
	Table A.48 present work	*Peters (1957)*	*Table A.48 present work*	*Ologhobo (1985)*	*Egbe and Treche (1984)*	*Onwueme (1978)*	*Table A.48 present work*	*Coursey (1983b)*
Number of samples and country	3 cv 9 samples Vanuatu	Adriano et al. (1932), Philippines	1 cv, 3 samples Vanuatu	1 sample Nigeria	9 samples Cameroon		1 cv, 3 samples	
Moisture %	82.5	80.0	65.7	71.2	66.6	60–70	80.7	—
Energy (kJ/100 g)	266	—	550	—	538	—	284	—
Protein %	1.65	2.3	1.42	1.30	2.34	1.1–2.0	1.52	2.54
Starch %	13.9	14.4	30.2	—	26.8	—	14.2	—
Sugar %	0.12	—	0.32	—	—	—	0.23	—
Carbohydrate % (diff.)	—	—	—	—	—	—	—	38
Dietary fibre %	0.66	—	0.63	—	0.87	—	1.02	—
Crude fibre %	—	0.4	—	0.34	—	0.4–0.8	—	—
Fat %	0.03	0.2	0.09	0.11	0.06	0.1	0.04	0.44
Ash %	0.76	1.1	0.73	0.98	—	0.7–2.6	0.70	—
Minerals (mg/100 g)								
Ca	13.4	—	4.6	5.6	6.0	—	8.0	—
P	26	—	28	6.0	31	—	38	—
Mg	23	—	17	11	18	—	15	—
Na	6.1	—	4.7	143	4.3	—	2.9	—
K	374	—	361	284	357	—	350	—
S	13	—	12	—	—	—	8.2	—
Fe	0.44	—	0.60	1.8	1.8	—	0.54	—
Cu	0.25	—	0.12	0.10	0.38	—	0.13	—
Zn	0.36	—	0.30	0.38	0.43	—	0.35	—
Mn	0.05	—	0.03	0.77	—	—	0.03	—
Al	0.62	—	0.63	—	—	—	0.41	—
B	0.17	—	0.08	—	—	—	0.11	—
Vitamins (mg/100 g)								
Vitamin A (ret. + β-car./6)	—	—	—	—	—	0.8	—	—
Thiamin	—	0.036[a]	—	—	—	—	—	—
Riboflavin	—	0.018[a]	—	—	—	—	—	—
Nicotinic acid	—	0.33[a]	—	—	—	—	—	—
Vitamin C	—	tr.[a]	—	—	—	6–12	—	—
Limiting amino acids + score								
First	—	—	S-contg. 60[b]	—	—	—	S-contg. 52[b]	Trp 64[c]
			Lys 82[c]	—	—	—	—	—
Second	—	—	Lys 91[b]	—	—	—	Lys 79[b]	Lys 72[c]

[a] Results obtained from Miller et al. (1956).
[b] Results obtained from Splittstoesser et al. (1973a).
[c] Results obtained from Francis et al. (1975).

Table 3.14. Composition of cassava tubers from Solomon Islands, Fiji and PNG (present work) and from literature sources, and of edible cassava leaves.

	Cassava tubers									*Cassava, edible leaves*		
	Present work											
	Table A.49	*Table A.50*	*Table A.51*	*Mean*	*Onwueme (1978)*	*Rickard and Coursey (1981)*	*Parkinson (1984a)*	*Odigboh (1983)*	*Ekpenyong (1984)*	*Onwueme (1978)*	*Oomen and Grubben (1978)*	*Gomez and Valdivieso (1985)[a]*
Number of samples and country	9 cv, 27 samples Solomon Is.	5 cv, 25 samples Fiji	6 cv, 30 samples PNG		Range of values	Mean of results from 4 sources			Several samples, Nigeria			4 cv, 32 samples Colombia
Moisture %	66.2	61.6	60.7	62.8	62.0	62.3	65.5	62.5	65.2	80	81	74.8
Energy (kJ/100 g)	528	600	611	580	—	578	565	610	568	209	251	—
Protein %	0.64	0.54	0.40	0.53	1–2	0.93	1.0	1.2	1.5	6	6.9	5.1
Starch %	28.0	31.9	33.2	31.0	—	—	—	—	—	—	—	—
Sugar %	1.14	1.00	0.34	0.83	—	—	—	—	—	—	—	—
Carbohydrate % (diff)	—	—	—	—	35	33.6	32.4	34.7	32.8	7	—	—
Dietary fibre %	1.43	1.45	1.57	1.48	—	—	—	—	—	—	—	—
Crude fibre %	—	—	—	—	1–2	—	—	—	0.9	—	2.1	5.1
Fat %	0.13	0.20	0.16	0.17	0.3	0.3	—	0.3	0.1	1	—	2.0
Ash %	0.69	0.96	0.86	0.84	1	—	—	—	0.5	—	—	2.7
Minerals (mg/100 g)												
Ca	19	19	22	20	—	29	26	33	30	200	145	350
P	31	—	61	46	—	52	32	—	31	—	—	56
Mg	29	—	30	30	—	—	—	—	—	—	—	—
Na	8.1	—	6.2	7.2	—	—	—	—	—	—	—	—
K	238	—	365	302	—	—	394	—	—	—	—	—
S	7.4	—	5.4	6.4	—	—	—	—	—	—	—	—
Fe	0.28	0.21	0.20	0.23	—	0.75	0.9	0.7	1.0	300	2.8	—
Cu	0.13	—	0.14	0.14	—	—	—	—	—	—	—	—
Zn	0.46	—	0.50	0.48	—	—	—	—	—	—	—	—
Mn	0.06	—	0.05	0.06	—	—	—	—	—	—	—	—
Al	2.60	—	1.06	1.83	—	—	—	—	—	—	—	—
B	0.06	—	0.07	0.07	—	—	—	—	—	—	—	—
Vitamins (mg/100 g)												
Vitamin A (ret. + β-car./6)	—	—	—	—	—	tr	0	tr	—	3	1.4	—
Thiamin	—	—	—	—	—	0.04	0.05	0.06	—	0.2	—	—
Riboflavin	—	—	—	—	—	0.06	0.04	0.03	—	0.3	—	—

Nicotinic acid	—	—	—	—	—	0.6	0.6	0.6	—	1.5	—	—
Pot. Nic. Acid = Trp/60	0.07	—	—	—	—	—	—	—	—	—	—	—
Ascorbic acid (AA)	9.7	—	—	9.7	—	—	—	—	—	—	—	—
Dehydroascorbic acid (DAA)	5.2	—	—	5.2	—	—	—	—	—	—	—	—
Total vitamin C (AA + DAA)	14.9	—	—	14.9	35	34(5)	34	36	—	200	80	—
Limiting amino acids and scores (Table A.52)												
First	—	—	—	His 80	—	—	—	—	Leu 61	—	—	Lys 99(8)
Second	—	—	—	Leu 85	—	—	—	—	Phe + Tyr 64	—	—	—
Organic acid anions (mg/100 g)												
Total oxalate (Ox)	48(14)	—	29(5)	39	—	—	—	—	—	—	—	—
Soluble oxalate	—	—	17(3)	17	—	—	—	—	—	—	—	—
Calcium oxalate	—	—	17	17	—	—	—	—	—	—	—	—
Free calcium	—	—	17	17	—	—	—	—	—	—	—	—
Malate	206(95)	—	438(354)	322	—	—	—	—	—	—	—	—
Citrate	388(159)	—	258(142)	323	—	—	—	—	—	—	—	—
Succinate	—	—	343(335)	343	—	—	—	—	—	—	—	—
Cyanide (mg/100 g)[b]												
free	3.57	0.69	2.69	2.13	—	—	—	—	—	—	—	—
total	3.66	2.54	2.78	3.10	—	—	—	—	—	—	—	18–180
Trypsin inhibitor (TIU/g)	<0.1	—	—	<0.1	—	—	—	—	—	—	—	—
Edible matter (prop. of wt purchased)	—	—	—	0.8–0.9	—	—	—	—	—	—	—	—

[a] Results recalculated to fresh basis and amino acid analyses recalculated using FAO/WHO/UNU (1985) values.

[b] Fiji results for cyanide obtained on fresh cassava, Solomon Islands and PNG results obtained on samples stored at −20 °C for 4–8 months.

sweet potato (Table 3.1) and taro (Table 3.3). The present work has filled gaps for cassava tubers in analyses for starch, sugar, dietary fibre, many minerals and organic acids. Our results show a protein content which is only one - half of that given by other workers. Because of the particularly low protein results for cultivars from PNG (Appendix Table A.51), we repeated Kjeldahl nitrogen analyses on the 30 samples and the results given are mean values. This low protein result is of particular concern for people whose diet is devoid of a high protein source such as animal protein, beans or at least edible green leaves. Our results for iron and vitamin C are less than one-half of those reported by other workers. It was shown that the yellow colour in yellow-pigmented cassava cultivars from Africa and South America was due to β-carotene, a precursor of vitamin A (Safo-Kantanka et al. 1984). The amount of β-carotene in yellow cassava tubers was as much as 1 mg/100 g on a dry weight basis, about 100 times the amount present in white tubers (McDowell and Oduro 1983). The amounts of soluble oxalate and calcium oxalate are low compared with other root crops, and there is a reasonable amount of free calcium for utilisation in human nutrition. The amounts of malate, citrate and succinate are about equal and much higher than total oxalate. The trypsin inhibitor content is negligible.

In comparing the analyses of cassava from Solomon Islands, Fiji and PNG given in Appendix Tables A.49, A.50 and A.51 respectively, we found that the Solomon Islands samples contained significantly more moisture and therefore less energy than those from Fiji and PNG. The PNG samples which are very high-yielding (70–100 t/ha) are the driest, and also have less protein than the cultivars from Solomon Islands and Fiji which gave lower yields. Perhaps the higher yields of PNG cassava are due to bulking of large amounts of storage carbohydrate, which decreases the protein content of the tuber, compared to cassava from Solomon Islands and Fiji.

The amino acid analyses given in Appendix Table A.52 show that the PNG samples have a larger amount of non-essential amino acids such as aspartic and glutamic acid, alanine and serine than the Solomon Islands samples. Differences in amino acid composition between the six different cultivars are also large and there is no essential amino acid which is clearly the first limiting amino acid, such as occurs with most other root crops. Nevertheless, on the average, histidine is the first limiting amino acid with a chemical score of 80, leucine is second (85) and tryptophan third (88). It should be noted that the variability of the results is such that none of these scores are significantly different from one another. Results of other workers (recalculated using the new FAO/WHO/UNU (1985) values) give leucine first limiting with a chemical score of 61 (Ekpenyong 1984) and S-containing amino acids as first limiting with a chemical score of 28 (Splittstoesser et al. 1973b). The low value for S-containing amino acids of Splittstoesser et al. (1973b) is probably due to large losses of cystine on hydrolysis, which could have been overcome by a separate analysis for cystine (section 2.5). Cassava contains protein of good quality with a chemical score of 61–80.

Analyses for total cyanide on individual tubers of cassava from Solomon Islands, Fiji and PNG gave a range of values from 0.7–9 mg/100 g fresh weight and the averages in Appendix Tables A.49 to A.51 from these individual results range from 1.3 to 6.3 mg/100 g. These values are in agreement with those of Mason (1956) for Fiji cassava of 2–9 mg/100 g, but his method of determination was not recorded. His value of 3 for cultivar Sokobale agrees well with our value of 2.7 mg/100 g for the same cultivar given in Appendix Table A.50. Mason (1956) also found about ten times as much cyanide in the cassava peel as in the flesh of the tuber. The South Pacific cassava cultivars are therefore classified as sweet cassava. The bitter cultivars which occur along with sweet cassava in Africa (Cooke et al. 1978), South America (Miranda et al. 1981) and Asia (Fukuba and Mendoza 1982) have cyanide contents up to 100 mg/100 g fresh weight.

Not only is cyanide a lethal poison at a dose rate of 0.5–3.5 mg HCN/kg body weight, but ingestion of small amounts over a period of time may produce chronic conditions discussed in section 5.1. Methods for the reduction of cyanide content of cassava tubers by cooking are therefore important, as is the possibility of obtaining a cultivar whose tubers are free of cyanide (section 5.1). Of the 20 South Pacific cultivars, and 80 tubers studied, L12 from PNG gave one tuber with 0.7 mg HCN/ 100 g and two other cultivars L19 (PNG) and New Guinea (Fiji) gave tubers containing <1 mg/100 g. Because of these low values obtained in this preliminary survey, it would be useful to screen all the South Pacific cultivars for acyanogenesis (section 5.1).

In Appendix Tables A.49–A.51, the total cyanide consists of free cyanide (present as HCN and cyanohydrin) and cyanide which is bound in a glucoside called linamarin (see section 5.1). Analyses made on fresh cassava tubers from Fiji (Appendix Table A.50) showed that about one-quarter to one-third of the total cyanide was free and the remainder was bound, whereas cassava tissue that was stored at −20 °C for 5 months before analysis gave an average loss of cyanide of 20% over four cultivars (20 samples). Results in Appendix Tables A.49 and A.51 are on samples that had been stored at −20 °C and under these conditions the bound cyanide (linamarin) was nearly all converted to free cyanide. Kawabata et al. (1984) found that during storage of cassava tubers at ambient temperatures, the linamarin content first increased and then decreased to zero before the tuber decayed. Rao and Hahn (1984) found that when 0.1 *M* phosphoric acid extracts containing free and bound cyanide were stored for 1 month at 4 °C, there was an increase in free cyanide but no loss of total cyanide.

As observed with various other root crops (see above), there are also significant differences in composition between different cultivars of cassava grown in the same environment. In each of Appendix Tables A.49, A.50 and A.51 there are significant differences in moisture, starch, energy, protein, dietary fibre and sugar between different cultivars, and between calcium, iron and cyanide in Appendix Table A.49. These significant differences between cultivars are a necessary prerequisite for a selection/breeding program such as that at the International Institute of Tropical Agriculture (Hahn et al. 1979; Hahn and Keyser 1985).

The composition of cassava leaves from literature sources is given in Table 3.14 and there is a wide spread of values for moisture, vitamin C and particularly for iron. The iron content of 2.8 mg/100 g is more likely to be correct than the value of 300, because it is about the level present in other leaves. The cyanide content of leaves is not significantly different from that of the tubers and there are no significant differences in cyanide content with time of harvest from 6 to 14 months (Cooke and De La Cruz 1982). The use of edible cassava leaves as a green vegetable is popular in Africa (Hahn 1984) but is not so important in the South Pacific.

3.8 Comparisons of Chemical Compositions of Tubers and Corms of All Root Crops

The average results over all tubers and corms for all root crops are given in Table 3.15, and are shown in Fig. 3.1 and 3.2. It is noted that energy and starch content are linked, as would be expected because 80–90% of the energy of the root crop comes from the large amount of starch present. Also as shown by Bradbury (1986), the energy content is inversely related to the moisture content (Table 3.15). Giant swamp taro and elephant foot yam have large amounts of calcium, total oxalate and calcium oxalate, and yam has small amounts of calcium and total oxalate. The results may be considered either with regard to the different nutrients or in terms of the different root

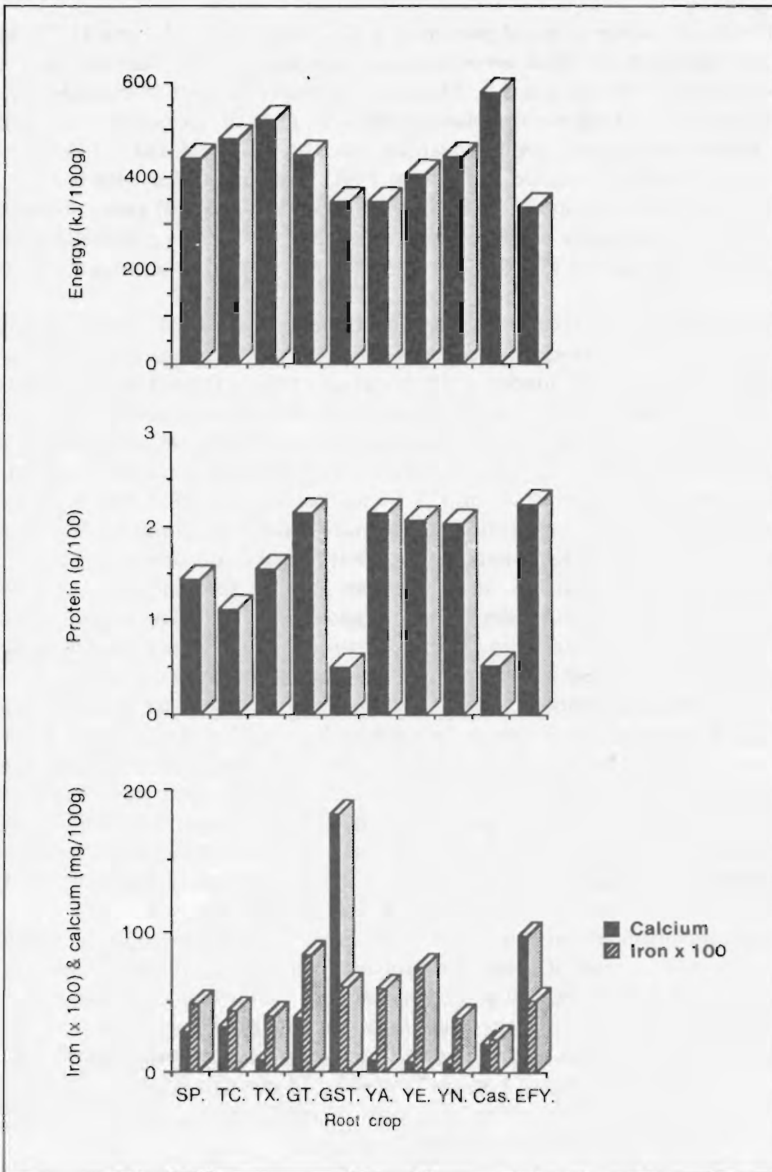


Figure 3.1. Comparison of the energy, protein, iron and calcium contents of the major root crops, viz. sweet potato (SP.), taro *Colocasia* (TC.), taro *Xanthosoma* (TX.), giant taro (GT.), giant swamp taro (GST.), elephant foot yam (EFY.), yam *D. alata* (YA.), yam *D. esculenta* (YE.), yam *D. nummularia* (YN.) and Cassava (Cas.).

crops. Depending on the end use, the data in Table 3.15 may be used in either of these ways, and we will now make comparisons between the different root crops.

Sweet Potato This species has the highest sugar and thiamin content, and is near the top for other vitamins (Fig. 3.2). It falls in the middle range for energy, protein, starch, dietary fibre and minerals. Overall, it has better than average nutritional characteristics and the only antinutritional factor present, trypsin inhibitor, is inactivated by cooking (section 5.2.5).

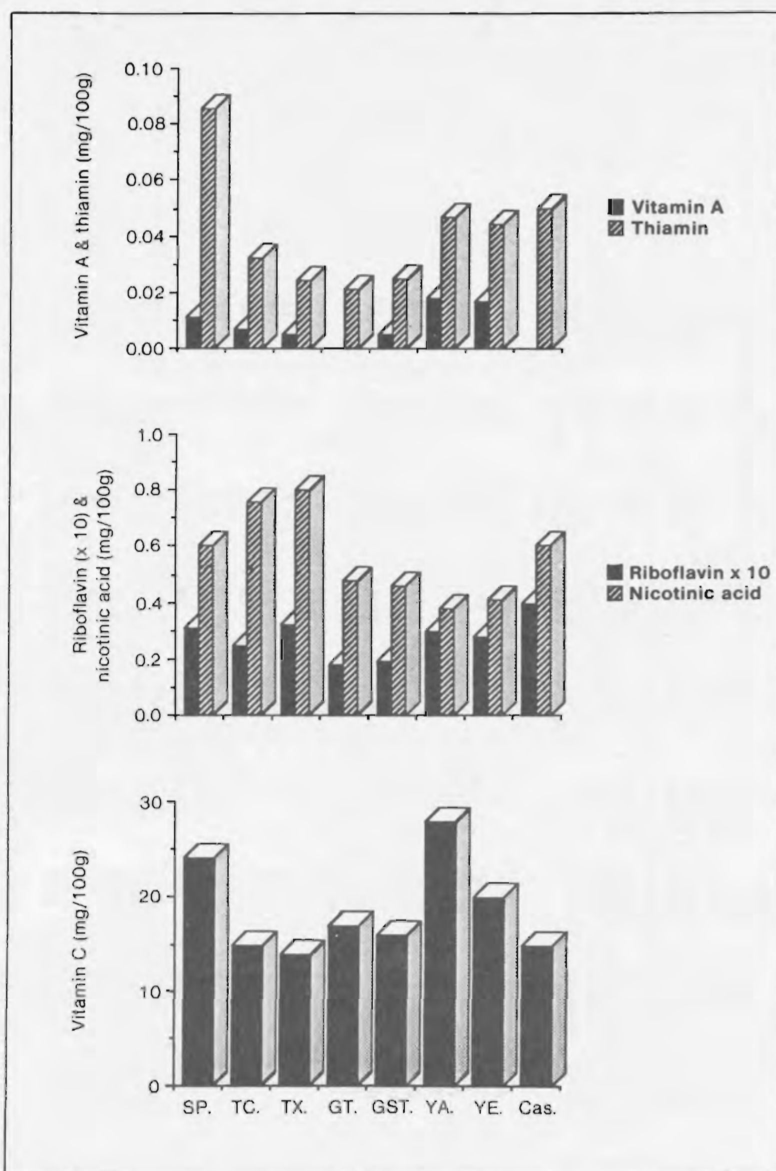


Figure 3.2. The vitamin contents of the major tropical root crops compared using the same abbreviated titles described in the legend of Fig. 3.1.

Taro Colocasia This root crop has a slightly higher energy content and lower protein content than sweet potato, the highest content of P, Mg and Zn of any root crop, and less of all vitamins (except nicotinic acid) than sweet potato. It is therefore slightly inferior to sweet potato but has good nutritional characteristics except for the problem of acridity of some cultivars, which is common to other aroids, and is removed by cooking (section 5.4).

Taro Xanthosoma The cormels of this species are slightly superior to taro *Colocasia* in energy and protein but contains much less Ca, Mg, Zn and trypsin inhibitor than taro *Colocasia*. All of the calcium present is combined as calcium

Table 3.15. Composition of tubers and corms of different root crops from present work.

		Aroids					*Yam*							
	Sweet potato	*Taro C. esculenta*	*Taro X. sagittifolium*	*Giant taro A. macrorrhiza*	*Giant swamp taro C. chamissonis*	*Elephant foot yam A. campanulatus*	*D. alata*	*D. esculenta*	*D. nummularia*	*D. bulbifera*	*D. pentaphylla*	*D. rotundata*	*D. trifida*	*Cassava M. esculenta*
Reference, number of samples and countries	Table 3.1 164 samples from 5 countries	Table 3.3 71 samples from 3 countries	Table 3.5 37 samples, from 2 countries	Table 3.6 37 samples, from 2 countries	Table 3.8 27 samples, from 2 countries	Table 3.9 7 samples one cv	Table 3.10 16 cv from 3 countries	Table 3.11 99 samples from 2 countries	Table 3.12 25 samples from 2 countries	Table 3.12 12 samples from Vanuatu	Table 3.13 9 samples from Vanuatu	Table 3.13 3 samples from Vanuatu	Table 3.13 3 samples from Vanuatu	Table 3.14 82 samples from 3 countries
Moisture %	71.1	69.1	67.1	70.3	75.4	77.8	77.3	74.2	71.9	81.7	82.5	65.7	80.7	62.8
Energy (kJ/100 g)	438	480	521	449	348	336	347	406	443	258	266	550	284	580
Protein %	1.43	1.12	1.55	2.15	0.51	2.24	2.15	2.06	2.04	1.94	1.65	1.42	1.52	0.53
Starch %	20.1	24.5	27.6	21.5	16.8	16.6	16.7	19.3	23.2	11.7	13.9	30.2	14.2	31.0
Sugar %	2.38	1.01	0.42	0.96	1.03	0.14	1.03	0.55	0.22	0.20	0.12	0.32	0.23	0.83
Dietary fibre %	1.64	1.46	0.99	1.85	2.78	1.45	1.88	1.15	1.84	1.42	0.66	0.63	1.02	1.48
Fat %	0.17	0.10	0.11	0.10	0.16	0.06	0.08	0.06	0.06	0.05	0.03	0.09	0.04	0.17
Ash %	0.74	0.87	1.04	0.92	0.67	1.36	0.81	0.82	0.95	0.69	0.76	0.73	0.70	0.84
Minerals (mg/100 g)														
Ca	29	32	8.5	38	182	97	8.2	7.5	6.5	8.4	13	4.6	8	20
P	51	70	53	44	16	67	38	39	40	27	26	28	38	46
Mg	26	115	27	52	21	47	17	26	20	19	23	17	15	30
Na	52	1.8	6.6	30	72	4.1	3.3	3.1	8.6	2.7	6.1	4.7	2.9	7.2
K	260	448	530	267	67	622	318	303	448	346	374	361	350	302
S	13	8.5	7.9	12	3.3	12	12	16	15	9.0	13	12	8.2	6.4
Fe	0.49	0.43	0.40	0.83	0.61	0.51	0.60	0.75	0.38	0.56	0.44	0.60	0.54	0.23
Cu	0.17	0.18	0.19	0.07	0.11	0.18	0.15	0.17	0.34	0.21	0.25	0.12	0.13	0.14
Zn	0.59	3.8	0.52	1.57	2.3	1.05	0.39	0.46	0.50	0.31	0.36	0.30	0.35	0.48
Mn	0.11	0.35	0.17	0.62	0.69	0.31	0.04	0.24	0.04	0.13	0.05	0.03	0.03	0.06
Al	0.82	0.38	0.53	0.36	1.36	0.41	0.64	0.51	0.29	0.49	0.62	0.63	0.41	1.83
B	0.10	0.09	0.09	0.10	0.09	0.17	0.09	0.07	0.05	0.10	0.17	0.08	0.11	0.07
Vitamins (mg/100 g)														
Vitamin A (ret. + β-car./6)	0.011	0.007	0.005	0	0.005	0.07[a]	0.018	0.017	—	—	—	0.8[a]	—	tr[a]
Thiamin	0.086	0.032	0.024	0.021	0.025	0.06[a]	0.047	0.045	—	—	0.036[a]	—	—	0.05[a]
Riboflavin	0.031	0.025	0.032	0.018	0.019	0.05[a]	0.030	0.028	—	—	0.018[a]	—	—	0.04[a]
Nicotinic acid	0.60	0.76	0.80	0.48	0.46	1.2[a]	0.38	0.41	—	—	0.33[a]	—	—	0.6[a]
Pot. Nic. Acid = Trp/60	0.32	0.19	0.33	0.46	0.07	—	0.44	0.66	—	—	—	—	—	0.07
Total vitamin C (AA + DAA)	24	15	14	17	16	3.8[a]	28	20	—	—	tr[a]	6-12[a]	—	15

Limiting amino acids + score														
First	Lys 70	Lys 66	Lys 57	Lys 64	Lys 70	—	Lys 71	Lys 59	Lys 64	—	—	S-contg. 60[b] Lys 82[c]	S-contg. 52[b] Trp 64[c]	His 80
Second	Leu 80	Thr 94 Ileu 93	Leu 81	His 91	Leu 97	—	Leu 91	—	—	—	—	—	—	Leu 85
Organic acid anions and calcium oxalate (mg/100 g)														
Total oxalate (Ox)	59	65	42	42	319	288	18	13	—	—	—	—	—	29
Soluble oxalate	38	35	44	17	45	25	—	—	—	—	—	—	—	17
Calcium oxalate	32	43	23	37	399	382	—	—	—	—	—	—	—	17
Free calcium	20	10	0	15	10	8	—	—	—	—	—	—	—	17
Malate	148	107	211	320	106	513	105	83	—	—	—	—	—	322
Citrate	124	102	314	278	86	256	142	123	—	—	—	—	—	323
Succinate	472	168	506	370	295	339	0	0	—	—	—	—	—	343
Trypsin inhibitor (TIU/g)	13	14	0.3	269	2.5	—	0.56	0	—	—	—	—	—	<0.1
Chymotrypsin inhibitor (CIU/g)	0–1	0	0	57	0	—	—	0	—	—	—	—	—	—

[a] Literature values.
[b] Splittstoesser et al. (1973a).
[c] Francis et al. (1975).

oxalate, which may have adverse consequences for human nutrition. Apart from these differences, this root crop is generally similar to taro *Colocasia*.

Giant Taro This species has one of the highest protein contents of any root crop (one sample from Western Samoa recorded 4.87%—ACIAR/ANU Program 1986) which is due mainly to a large amount of trypsin/chymotrypsin inhibitor (section 5.2.3; Hammer 1987). Its energy content is similar to that of sweet potato and taro *Colocasia*. Compared with other root crops it is high in trypsin inhibitor, Ca, Fe, Zn, Mn, malate, citrate and succinate and low in K, Cu, thiamin and riboflavin and has no detectable amount of vitamin A (β-carotene). The large amount of trypsin/chymotrypsin inhibitor would reduce the digestibility by animals of the protein of uncooked giant taro, but the inhibitor is inactivated on prolonged cooking, hence the high protein content is advantageous for human nutrition. However, this needs to be balanced against the low levels of some vitamins, particularly vitamin A and the acridity of this root crop (see section 5.4).

Giant Swamp Taro Compared with other root crops, giant swamp taro has the highest content of dietary fibre, Ca, Na, Mn, total oxalate and calcium oxalate and is high in Fe and Zn, but has the lowest amount of protein (with cassava), P, K and S and low amounts of energy, Cu, vitamin A and most other vitamins. The high Ca and Na, and low K contents may reflect the fact that this root crop is largely grown on coral atolls. Because of its low protein, energy, vitamin and very high calcium oxalate content, it must be considered nutritionally inferior to the other root crops. However, in combination with fish and (to provide vitamins) edible green leaves, it would provide an acceptable diet in the atolls, where the environment is often unsuitable for the growth of other root crops.

Elephant Foot Yam This species has the largest amount of protein, K and malate of any root crop, and also large amounts of Ca, calcium oxalate, P, Mg, Zn and (based on literature data) of vitamins compared with other root crops. However, it has a high moisture content and thus is low in energy. This aroid is also acrid. Results should be interpreted cautiously because only one cultivar was analysed.

Yam (D. alata) This species of yam has the equal second largest amount of protein and large amounts of dietary fibre, vitamin A and vitamin C, and low amounts of Ca, P, Mg, Na, Mn, nicotinic acid, oxalate and trypsin inhibitor compared with other root crops. The low Ca content was also found by Ologhobo (1985). The Fe content is variable with a high value for tubers from Western Samoa and a low value for tubers from PNG (Table 3.10). This root crop is desirable compared with others because of its high level of protein, vitamin A, vitamin C and dietary fibre, and small amounts of oxalate and trypsin inhibitor, but we should also note the small amounts of nicotinic acid and some minerals.

Yam (D. esculenta) This root crop contains large amounts of protein, S, Fe, vitamin A and vitamin C and small amounts of Ca, Na, K, nicotinic acid, oxalate, malate and succinate compared with other root crops, and no trypsin inhibitor. It is nutritionally very similar to *D. alata* but contains slightly more energy and Fe, slightly less protein, and much less dietary fibre.

Yam (D. nummularia) This crop is high in protein, dietary fibre, Na, K, S, Cu and low in Ca, Fe and Mn compared with other root crops. Its energy and moisture contents are in the middle range. Data are not available on vitamins or organic acids. It is nutritionally similar to *D. alata* but contains more energy, Na, K and Cu, and less Fe than *D. alata*.

Yam (D. bulbifera) This species has nearly the highest moisture content, high levels of protein and Cu, and the lowest amount of energy and starch and low levels of sugar, Ca, P, Mg, Na and Zn. Results are not available for vitamins, organic acids and

amino acids. However, the high moisture content and low energy observed in our samples from Vanuatu was not found in cultivars from Africa (see Table 3.12). Apart from this obvious difference, *D. bulbifera* appears to be nutritionally similar to *D. alata*.

Yam (D. pentaphylla) This root crop has the highest moisture content, which is also confirmed by literature data (Table 3.13), is high in S and Cu, and low in energy, starch, sugar, dietary fibre, P, Zn, riboflavin, nicotonic acid and vitamin C. The vitamin results are from literature sources. It is nutritionally different and inferior compared with *D. alata* and the other yams in having a consistently higher moisture content (lower energy), protein and Ca contents in the middle of the range and low values for dietary fibre and several vitamins.

Yam (D. rotundata) This species is the driest of the yams (confirmed by literature results—Table 3.13) in contrast to *D. pentaphylla* which is the wettest. *Dioscorea rotundata* contains a large amount of energy, starch and Fe, the smallest amount of dietary fibre, Zn and Ca of any root crop, and small amounts of P, Mg, Cu and Mn. The protein content is in the middle range. Nutritionally it is a good root crop with high energy, acceptable protein and Fe contents, but is lowest in Ca and Zn. More data are required on vitamins and organic acids.

Yam (D. trifida) This root crop has high moisture content and hence low energy. It is also low in starch, Ca, Mg, Na, Cu, Zn and Mn compared with other root crops. The protein content is in the middle range. These results should be treated cautiously because they were obtained from only one cultivar and there is a dearth of data in the literature.

Cassava The driest root crop is cassava, hence it has the highest energy and starch content. It also has a high content of dietary fibre, Mg, Na, riboflavin, thiamin, nicotinic acid and citrate, and the lowest amounts of protein and Fe. It is also low in K, S and vitamin A compared with other root crops and contains no trypsin inhibitor. The very low protein content of South Pacific cultivars is significantly less than that reported in the literature (Table 3.14), and may be alleviated by the slightly higher quality of the protein of cassava than that from other root crops (Table 3.15). Cassava combines high energy and high levels of some vitamins (data from the literature) with low amounts of protein, Fe, vitamin A and the added problem due to presence of cyanide in all tubers. Nutritionally, cassava is less desirable than any of the other root crops except perhaps giant swamp taro. The increasing popularity of cassava in the South Pacific clearly does not result from nutritional superiority, but from agricultural considerations, such as relative freedom from disease and insect attack, and its ability to give acceptable yields when grown under adverse conditions.

3.9 The Variability of Composition of Nutrients and Antinutritional Factors Across Tubers and Corms

The differences in the amount of a nutrient or of an antinutritional factor (such as cyanide in cassava) across a tuber or along its long axis are important for three reasons. First of all, gradients of composition across the tuber are important to the chemist, who needs to analyse a representative sample of the whole tuber to obtain a meaningful result. Second, gradients of nutrients or of antinutritional compounds may well be an important factor in determining the best way to prepare and cook the food. For example, it is common practice to take off a very thick peel from giant taro corms in order to remove most of the acrid material that tends to be concentrated in the surface layers (Wilson, J. E., pers. comm.). Third, the possible defensive role of antinutritional factors in the tuber against attack by organisms may be related to the

occurrence of gradients of concentrations of the constituent (see section 5.5, Hammer 1987).

No systematic study has been made of gradients of concentration of nutrients in tropical root crops, but there have been a number of scattered observations. This literature data will now be considered along with our own work, under the heading of the particular root crop.

Sweet Potato Longitudinal gradients of protein content with a significantly higher concentration (20–30%) at the stem (proximal) end were observed for two cultivars but not for a third (Purcell et al. 1976b). Radial gradients from the skin in to the centre of the tuber were not significant, except for a higher protein content in the outer layer, the thickness of which is equal to 0.1 × the radius of the tuber. This was confirmed by Bradbury et al. (1984a) who found that the protein content of the skin was 50–90% higher than that of the remaining tuber. There was no evidence of gradients in the third direction around the circumference (Purcell et al. 1976b). The thiamin content was about twice as large 2–3 mm below the skin as at the centre of the tuber, and there was no longitudinal gradient. The riboflavin content was constant throughout the tuber (Bradbury and Singh 1986b).

Giant Taro Because of the large size of the corm (typically 1 m long, 15–20 cm diameter; see section 1.1.4), measurements of possible gradients of moisture, protein, vitamins, calcium, iron, oxalate and trypsin inhibitor have been determined. Two cultivars had a longitudinal gradient of moisture with low values at the stem (proximal) end increasing towards the root (distal) end, but one cultivar had a longitudinal gradient of moisture in the opposite direction. This cultivar also showed a decrease in moisture content from the outer layers inwards to the pith at the centre. There was no longitudinal gradient for protein and a small but not significant increase of protein content from the skin towards the centre. There was evidence of a decrease in iron content from the distal to the proximal end of the corm but no longitudinal gradients of calcium, fat, ash (ACIAR/ANU Program 1984), thiamin or riboflavin. The concentration of thiamin (Bradbury and Singh 1986b) and oxalate (section 5.3.2) was higher near the skin than at the centre, whereas the reverse was observed for trypsin inhibitor (section 5.2.4).

Yam (Five Species) Ologhobo (1985) found that for moisture there was an increase and for protein and iron (recalculated on basis of fresh weight) there was a decrease from the proximal (head) to the distal (tail) end of the yam tuber. On a fresh weight basis, the peel contained much more fibre and ash, 2–3 times the amount of protein, 4–5 times as much calcium and twice as much iron as the tuber.

Cassava The amount of cyanogenic glucosides in cassava was up to ten times greater in the outer part (near the peel) than at the centre of the tuber and the disparity in concentration was more marked in the less toxic than the more toxic cultivars (de Bruijn 1971; Cooke 1978). The large radial gradient of linamarin across the tuber was also found with linamarase (Kojima et al. 1983). There was also a smaller gradient of concentration observed in the longitudinal direction.

Chapter 4.
Effects of Cooking and Storage

Many foods including the root crops cannot be digested in their natural state and hence require cooking, which increases the palatability, digestibility, the keeping qualities and the safety of the foods. These clear advantages are achieved at some cost, however, since the nutritive value of the food may be reduced as a result of chemical changes in the proteins, carbohydrates, fats and vitamins present, and in some cases, potentially toxic substances may be produced. In this chapter we are concerned with the changes that occur in the nutritive value of food as a result of cooking, with particular reference to the tropical root crops and to the methods of cooking that are normally used in the South Pacific region.

Another very important matter is the storage of food. This, like cooking, has been practiced by people for many centuries. We will focus here only on the deterioration that may occur during storage of tropical root crops, and also on the loss of nutrients during storage. We have little data of our own, and would suggest that there are considerable gaps in knowledge in this field.

4.1 Changes Produced by Cooking

Cooking exposes the food to heat either in a dry form (baking in an oven or in the coals of an open fire) or in a wet form such as occurs by boiling, steaming or frying in oil or fat. We will not be concerned with frying in fat because this process is not important in the South Pacific. Considerable work has been done on the chemical changes produced by frying (Passmore and Eastwood 1986; Nawar 1985).

The changes produced by cooking may be conveniently divided into those brought about by heat and those brought about by the effect of water or steam on the food. The heating process has the very desirable effects of at least partially sterilising the food by killing bacteria and other potentially harmful microorganisms, and also of increasing the availability of nutrients. For example, the cellulosic cell walls of plant foods are not readily broken down in the gut of monogastric animals, such as humans, but these cell walls are degraded by heat and the nutrients within are made available (Bradbury et al. 1984b; Passmore and Eastwood 1986). Heating also solubilises starch and makes it more available. Proteins are irreversibly denatured by heating at 100 °C and this causes insoluble collagen, present in the connective tissue of animals, to be denatured to gelatin, which is much more readily available because it may be attacked by the proteolytic enzymes of the small intestine. Similarly, enzyme inhibitors present in animal and plant foods, including many tropical root crops, are denatured (inactivated) at 100 °C and hence are no longer able to inhibit the action of enzymes such as trypsin, which is involved in the digestion of protein in the small intestine (section 5.2.5). There are, however, a number of deleterious chemical reactions such as the chemical degradation of vitamins that occur as a result of heating. Another example is the reduced availability of essential amino acids such as lysine, which is due to the

Maillard reaction between reducing sugars and the amino groups of proteins and amino acids (Cheftel et al. 1985).

The specific effect of water or steam may include chemical changes produced by chemical reactions with water (called hydrolysis reactions) as well as its effect as a solvent in simply dissolving water-soluble nutrients from the food. The latter effect includes solubilisation of the water-soluble vitamins (vitamin C, thiamin, riboflavin and nicotinic acid—Bradbury and Singh 1986a, b), as well as water-soluble minerals (Na, K, and possibly other elements present as water-soluble salts or other compounds in the food). Other water-soluble compounds such as amino acids or sugars may also be dissolved in the cooking water. In developed countries, it is usual to discard the cooking water, with consequent loss of water-soluble nutrients, but in some societies it is customary to use a small volume of water and evaporate nearly to dryness such that the constituents would be absorbed by the cooked food, or else to use the cooking water in a soup or stew.

Some studies on the effects of cooking (boiling and/or baking) on the nutrients present have been made by others on sweet potato (Junek and Sistrunk 1978), yam and taro. Unfortunately in some cases analyses were made only on cooked root crops (Francis et al. 1975; Norgan et al. 1979), so that no comparison was possible between cooked and uncooked material, although in one of these cases, Purcell and Walter (1972) found a loss of lysine with canned and flaked as compared with baked sweet potato. Cooking of sweet potato causes formation of maltose by breakdown of starch catalysed by the enzyme amylase (Walter et al. 1975; Palmer 1982; Picha 1985b, 1986; Truong et al. 1986). Boiling of yam caused some removal of free amino acids present in yams (Splittstoesser 1976). Boiling produced a significant reduction in the amount of magnesium, phosphorus and occasionally iron in West African yams of different species (Bell 1983). Clearly, free amino acids and these minerals (combined as salts) were soluble in boiling water and hence were dissolved out of the root crop. It was found with rats that the availability of both carbohydrate and protein of taro *Colocasia* cormels was increased by cooking, as a result of the rupturing of cellulosic cell walls and the resultant increased availability of starch and protein (Hussain et al. 1984). We have studied the effect of cooking (boiling, steaming and baking) on the nutrients present in sweet potato, taro, yam and cassava (Bradbury et al. 1988a). Methods used for the removal of cyanide in cassava and the inactivation of trypsin inhibitor will be considered in Chapter 5.

4.2 Methods of Cooking Root Crops

4.2.1 Boiling, Steaming and Baking Sweet Potato, Taro, Yam and Cassava

Five tubers or corms of the root crop, which had been weighed immediately after harvest, were weighed again after arrival in Canberra to determine their weight loss during transport (see section 2.1). The tuber or corm was peeled and cut into four approximately equal cubic pieces of 60 g. Each piece was weighed accurately and given the following treatments: (1) control sample, no treatment; (2) the piece was placed in boiling water and boiled for 20 min; (3) steamed for 25 min; (4) baked (uncovered) in an oven at 200 °C for 30 min. The treatments simulated the major methods of cooking used in the South Pacific region, i.e. boiling in water, cooking wrapped in leaves in an earth oven over heated stones (a form of steaming—Parkinson 1984b) and cooking in the coals of a fire (somewhat equivalent to dry heating in an oven). Experiments showed that after the stated times of treatment, the root crop samples were well-cooked and edible. After treatment, the hot samples were allowed to dry in the air to

remove surface water and then were weighed. The control and cooked samples were diced or mashed and then either taken directly for analysis or deep frozen at -20 °C in plastic bags for later analysis. The results were at first calculated on the basis of the percent moisture present in the sample ('as is' basis), but in order to quantify changes due to cooking, the results for each tuber or corm were recalculated to the fresh moisture content for that tuber or corm.

4.2.2 Boiling and Baking Methods Used for Vitamin Analyses

Samples (~50 g) were added to boiling water and boiled for 10, 20 and 30 min. In one set of experiments the water was discarded, whereas in another the water was retained and evaporated to dryness in the presence of the boiled sample. The sample was then dried at 40 °C for analysis. For baking, samples (~50 g) were heated in an oven at 200 °C for 15, 30 and 45 min. These samples were then dried in an oven at 40 °C. After drying for 2–3 days at 40 °C to constant weight, samples were ground to a fine powder for analysis. A control sample was given the same processing treatment, but without boiling or baking. Samples were edible and well-cooked after 20 min boiling or 30 min baking (Bradbury and Singh 1986a, b).

4.3 Effects of Cooking on Nutrients in Sweet Potato, Taro, Yam and Cassava

Five tubers or corms of each different root crop were cut into four pieces and cooked by boiling, steaming and baking as described in section 4.2.1. Analyses were made for moisture, Kjeldahl nitrogen (% crude protein), ash, starch, dietary fibre, individual sugars by HPLC and minerals by ICP (see Chapter 2). The mean values for the control samples (which were not subjected to cooking) for each root crop are given in Tables 4.1–4.4. The tables also give the mean values of the differences, taken individually for each tuber or corm, between the boiled, steamed or baked value and the control value. Thus a positive difference for a particular nutrient indicates that the amount of that nutrient has increased on cooking and a negative difference shows a decrease as a result of cooking. All such differences were tested for statistical significance and the results are shown in the tables.

As discussed in section 4.1, changes in nutrient composition on cooking are related to the stability of the nutrient to heat, its solubility in boiling water and other factors that (with one exception for sweet potato) do not vary much from one root crop to another. Thus the differences in Tables 4.1–4.4 may be discussed on a nutrient-by-nutrient basis.

The moisture content of all root crops increased on boiling by 1–4% and in two out of the four cases steaming increased moisture content by about 2%. Dry baking at 200 °C decreased the moisture content in all cases by 7–9%. Such behaviour would be anticipated from the nature of the treatments. In every case, the ash content was reduced significantly by boiling which was consistent with the loss of water-soluble minerals, K, Na, P and S, presumably as potassium and sodium phosphates and sulfates. The extent of the loss of potassium and sodium always greatly exceeded that of phosphate and sulfate, which indicated the loss of other salts of potassium and sodium, probably mainly chlorides. The chloride content was not measured. Sodium was also lost in two cases after steaming and boron in two cases after boiling. Apart from these significant changes in mineral content on cooking, there were some other statistically significant changes which occurred only once over the four root crops. Because of their apparently random and occasional occurrence, these latter changes were considered to be due to experimental errors.

Table 4.1. Effect of cooking (boiling, steaming and baking) on composition of sweet potato.[a]

	Analysis of control	*Differences*		
		Boiled-control	*Steamed-control*	*Baked-control*
Moisture %	68.4 (2.9)[b]	4.3**	1.6*	-7.3**
Protein %	1.77 (0.24)	-0.04	0.07	0.22*
Ash %	0.76 (0.07)	-0.12**	-0.07*	0.04
Starch (st) %	21.3 (1.8)	-9.8**	-6.2**	-11.9**
Dietary fibre (DF) %	1.40 (0.20)	2.06**	2.07**	1.12*
Sugars %[c]				
Fructose %	0.33 (0.12)	-0.08*	-0.04	-0.07*
Glucose %	0.45 (0.11)	-0.06	-0.04	-0.08
Sucrose %	2.03 (0.58)	0.11	0.19	0.40
Maltose (Mlt) %	0.64 (1.02)	6.43**	6.88**	6.45**
Σ(st + DF + Mlt)	23.3	-1.31	2.75	-4.33
Minerals (mg/100 g)				
Ca	45 (6)	0.5	-6.7	-2.0
P	29 (3)	1.0	1.4	1.0*
Mg	36 (6)	2.8	-3.7*	-0.6
Na	73 (16)	-12.7	-10.4	-2.7
K	243 (19)	-36*	47**	37
S	13 (2)	1.1	1.1	0.8
Fe	0.70 (0.26)	-0.02	0.03	-0.06
Cu	0.22 (0.06)	0.02	-0.03	-0.03
Zn	0.29 (0.07)	-0.05**	0.01	0.06
Mn	0.26 (0.14)	0.01	-0.03	-0.01
Al	0.24 (0.12)	0.18	-0.10	-0.03
B	0.14 (0.02)	0.00	-0.01	-0.01

[a] Sweet potato from Tonga, April 1986, advanced trial at Vaini Research Station. Results of five tubers were averaged from cultivars 83003-12 (3 tubers), 83003-13 (1 tuber) and Hawaii (1 tuber). Differences showing one asterisk indicates a significant change on cooking, $P < 0.05$; two asterisks indicates $P < 0.01$.

[b] The value of 68.4 and variance in parentheses for moisture was that on harvesting in Tonga; the moisture content before cooking in Canberra was 63.4 (3.0)%.

[c] Total sugar (%): control, 3.45; boiled, 9.85; steamed, 10.44; baked, 10.15.

Dietary fibre increased very substantially after cooking which was considered to be due to the formation during cooking of some enzyme-resistant starch (Selvendran and Dupont 1984; Englyst and Macfarlane 1986). Because of the large amount of starch present compared with dietary fibre, this apparent increase in dietary fibre after cooking caused no significant change in starch. However, in the case of sweet potato, there was a highly significant reduction in starch content due to the large amount of breakdown of starch to maltose.

The 6.6% increase in maltose content of sweet potato on cooking clearly results from the breakdown of starch to maltose catalysed by amylases (Ikemiya and Deobald 1966). Quantitative agreement between the reduction in starch content and the increase in dietary fibre + maltose is not found in Table 4.1, because of the likely formation of appreciable amounts of oligosaccharides (not determined in this study) by the breakdown of starch catalysed by amylase. This large increase in maltose on cooking has been observed previously (Walter et al. 1975; Palmer 1982; Picha 1985b, 1986; Truong et al. 1986; Tamate and Bradbury 1985; Martin and Roberts 1983; Kawabata et al. 1984). However, Martin (1985) has reported staple-type sweet potato cultivars, in which the reducing sugar content (glucose + maltose) does not increase with cooking,

presumably because of a low concentration of amylase. The other root crops do not show evidence of breakdown of starch to maltose on cooking (Tables 4.2–4.4), which may be due to a low concentration of amylase or its absence in these cases. Changes in the content of other sugars on cooking are small compared with the large increase in maltose content of sweet potato.

The small decreases in sucrose, glucose and fructose contents on cooking does not agree with Kawabata et al. (1984) who found an increase in total sugar content on boiling and roasting of cassava. A possible explanation of the small decreases is slight degradation of sucrose on heating, which has been previously observed on extended drying at 40°C (Tamate and Bradbury 1985) and on cooking of samples of sweet potato (Truong et al. 1986).

4.4 Effects of Cooking on Vitamin Content of Sweet Potato, Taro and Giant Taro

The decrease in the content of water-soluble vitamins thiamin, riboflavin, nicotinic acid and vitamin C due to baking and boiling (in which the water is discarded or retained) is shown for sweet potato, taro and giant taro in Appendix Tables A.12, A.24

Table 4.2. Effect of cooking (boiling, steaming and baking) on composition of taro *Colocasia*.[a]

	Analysis of control	*Differences*		
		Boiled-control	*Steamed-control*	*Baked-control*
Moisture %	65.5 (1.0)[b]	4.4**	2.0*	-7.5**
Protein %	0.96 (0.15)	0.01	-0.06	0.05
Fat %	0.05 (0.03)	0.00	0.03	0.03
Ash %	0.76 (0.09)	-0.07*	0.01	0.05
Starch %	27.8 (1.2)	3.2	2.9	1.1
Dietary fibre %	1.22 (0.14)	0.82**	0.79**	0.77**
Sugars %				
Fructose %	0.10 (0.06)	-0.02	-0.01	-0.02
Glucose %	0.06 (0.02)	-0.01	-0.01	-0.01
Sucrose %	0.94 (0.16)	-0.08	-0.11	-0.13
Maltose %	0.10 (0.03)	-0.02	-0.01	-0.01
Raffinose %	0.03 (0.01)	0	-0.01	0
Minerals (mg/100 g)				
Ca	16 (3)	1.0	0.62	-0.90
P	33 (5)	1.1	4.1	4.5
Mg	32 (4)	-0.58	1.7	0.26
Na	3.4 (0.3)	0.93	0.95	-0.23
K	328 (36)	-41*	1.8	-6.0
S	5.4 (0.7)	-0.12	0.33	0.4
Fe	0.79 (0.18)	-0.06	-0.04	0.09
Cu	0.20 (0.07)	-0.02	-0.01	-0.02
Zn	0.47 (0.05)	0.02	0.05	0.08
Mn	0.14 (0.05)	0.02*	0.02*	0.03
Al	0.31 (0.13)	0.09	0.11	-0.14*
B	0.09 (0.04)	-0.02	-0.01	-0.01

[a] Five corms of cultivar Samoa from Fiji (July 1986) were cooked and results were averaged. Differences marked with one asterisk mean a significant change on cooking, $P < 0.05$; two asterisks indicates $P < 0.01$.

[b] The value of 65.5 was that on harvesting in Fiji; the moisture content before cooking in Canberra was 58.2 (1.7).

Table 4.3. Effect of cooking (boiling, steaming and baking) on composition of yam *D. alata*.[a]

	Analysis of control	*Differences*		
		Boiled-control	*Steamed-control*	*Baked-control*
Moisture %	76.6 (1.2)[b]	1.2*	-0.18	-6.8**
Protein %	1.78 (0.39)	-0.04	-0.01	0.03
Fat %	0.06 (0.05)	-0.01	0	-0.03
Ash %	0.75 (0.03)	-0.12**	-0.01	0.01
Starch %	18.6 (2.1)	0.58	-0.31	-0.36
Dietary fibre %	1.56 (0.44)	1.63**	1.60**	0.92*
Sugars %				
Fructose %	0.22 (0.09)	-0.07	-0.06	-0.08
Glucose %	0.16 (0.09)	-0.04	-0.05	-0.06
Sucrose %	0.51 (0.24)	0.14	0.07	0.09
Maltose %	0.08 (0.03)	0.01	-0.02	-0.02*
Raffinose %	0.04 (0.03)	0	0	0
Minerals (mg/100 g)				
Ca	6.0 (1.2)	-0.26	-0.99*	-0.47
P	39 (2)	-3.3**	0.84	-2.52
Mg	15 (1)	-0.80	0.22	-1.14
Na	5.8 (2.5)	-2.8*	-1.7*	-0.8
K	345 (20)	-63**	-7	-23
S	14 (1.0)	-1.7**	0.24	-0.10
Fe	0.65 (0.39)	0.10	-0.15	-0.13
Cu	0.17 (0.03)	-0.02	0	-0.01
Zn	0.32 (0.03)	0.01	-0.01	-0.03*
Mn	0.03 (0.01)	-0.01	-0.01	-0.01
Al	0.21 (0.11)	0	0.02	0.03
B	0.10 (0.01)	-0.02*	-0.01	-0.01

[a] Results are the average from cooking five tubers of cultivar Da 10, grown at University of South Pacific, Alafua, Western Samoa (see Appendix Table A.39). Differences marked with one asterisk mean a significant change on cooking, $P < 0.05$; two asterisks indicate a very significant change, $P < 0.01$.

[b] The value of 76.6 was the moisture content after harvesting in Western Samoa; the moisture content before cooking in Canberra was 75.2 (1.6).

and A.32 respectively. Clearly in every case, the longer the time of cooking the more vitamin was lost. Within the limits of experimental error, the vitamin loss was found to be independent of the type of root crop for the three root crops studied. Also the percentage losses of thiamin, riboflavin and nicotinic acid were found to be about the same. If one considers the losses when the root crops are well cooked (20 min boiling or 30 min baking), the results in Appendix Tables A.12, A.24 and A.32 may be summarised quite simply.

The losses of thiamin, riboflavin and nicotinic acid amounted to 40% on boiling if water was discarded, 20% if water was retained and 25% on baking. The loss of total vitamin C (ascorbic acid + dehydroascorbic acid) was about 65% on boiling if water was discarded, 20% if water was retained and 50% on baking (Bradbury and Singh 1986a, b). The losses of thiamin, riboflavin and nicotinic acid on cooking are important nutritionally because of the relatively small amount of these vitamins present compared with the recommended daily allowances of thiamin (1.4 mg), riboflavin (1.6 mg) and nicotinic acid (19 mg). A calculation of the amount of fresh root crop that would be needed to supply the recommended daily allowance of riboflavin (which is present in the least amount) showed that about 3–9 kg/day was required (Bradbury and Singh 1986b).

4.5 Cooking Methods and Human Nutrition

From the nutritional point of view, dry baking would appear to be superior to the other methods of cooking because the decrease of the moisture content would decrease the bulkiness of the food, which is important for young children since bulkiness may limit intake of energy and protein. Based on the moisture content of the cooked root crops in Tables 4.1–4.4, and the inverse relationship between moisture and energy (section 2.13), it is calculated that the baked root crop contains 30–40% more energy per gram than the boiled or steamed root crop. Furthermore, with baking there is no loss of minerals and less loss of vitamins than for boiling if water is discarded. However, boiling in water that is retained either in a soup or stew, or in the cooked material by evaporation, causes no loss of minerals and about the same loss of vitamins as in dry baking. Losses of minerals and vitamins during steaming (and in the earth oven system used in the South Pacific) would approximate those found on boiling with retention of water. Clearly, the largest losses in minerals (up to one-fifth of the potassium) and particularly vitamins, occurs by boiling if water is discarded. Finally, it should be noted that special methods of cooking may be required to remove cyanide from cassava (section 5.1.2) and to get rid of the acridity present in some aroids (section 5.4).

Table 4.4. Effect of cooking (boiling, steaming and baking) on composition of cassava.[a]

	Analysis of control	*Differences*		
		Boiled-control	*Steamed-control*	*Baked-control*
Moisture %	60.0 (2.5)[b]	3.0	0.08	-8.9**
Protein %	0.43 (0.07)	0	-0.03	0.11
Fat %	0.10 (0.06)	0.03*	0.06*	0.01
Ash %	0.91 (0.04)	-0.17*	0.02	0.09
Starch %	33.4 (4.2)	0.15	1.2	-0.8
Dietary fibre %	1.51 (0.25)	0.49*	0.22	0.53
Sugars %				
Fructose %	0.23 (0.08)	-0.06	0.04	-0.07*
Glucose %	0.27 (0.10)	-0.11*	0.04	-0.11*
Sucrose %	1.15 (0.22)	-0.33*	-0.31*	-0.39**
Maltose %	0.06 (0.03)	-0.01	-0.02	-0.01
Minerals (mg/100 g)				
Ca	15 (1)	-0.74	0.2	0.9
P	66 (7)	-8.6*	1.8	3.6
Mg	64 (10)	-7.5	2.9	17.8*
Na	11 (2)	-2.3**	-1.63*	-0.92
K	419 (21)	-89**	15	21
S	5.6 (0.6)	-0.77*	-0.06	0.16
Fe	0.13 (0.04)	-0.04	-0.03	0.03
Cu	0.06 (0.02)	0.01	0	0
Zn	0.48 (0.05)	0.23*	0.16	0.09
Mn	0.14 (0.01)	-0.01	-0.01	0.01
Al	0.31 (0.04)	-0.06*	-0.07*	-0.04
B	0.06 (0.01)	-0.01*	0	0

[a] Results are mean values from five tubers of cassava, cultivar New Guinea obtained from Fiji in July 1986 (see Appendix Table A.50 for details). Differences marked with one asterisk represent a significant change on cooking, $P < 0.05$; two asterisks indicate a very significant change $P < 0.01$.

[b] This moisture content was that obtained at harvest in Fiji and no change occurred during transit to Australia, because the cassava was packed in moist vermiculite to prevent deterioration.

4.6 Storage of Root Crops

Whereas the changes in nutrient composition of the different root crops as a result of cooking are similar (see section 4.3 and 4.4), the changes that occur in the fresh storage organs after harvesting vary considerably amongst different root crops. This is because of a range of biological factors (including respiration, senescence, attack by fungi and other microbiological agents) that are very different from one root crop to another, as well as biochemical and chemical processes that affect the concentrations of nutrients in the different species. It is therefore necessary to consider each root crop separately and to study the whole range of factors which affect storage.

The generally poorer storage qualities of root crops, compared with cereals and legumes, is a potential source of large postharvest losses. Although much work has been done there are still large gaps in our knowledge. Our contribution in terms of research has been small, however, and confined to changes in the vitamin C content of sweet potatoes on storage. Nevertheless, it is hoped that a short review on the storage of each root crop may be of some value.

4.6.1 Storage of Sweet Potato

There are two major types of sweet potato with different end uses and different storage requirements. First, there are the white-fleshed, less-sweet varieties that are used as staple foods in the South Pacific and elsewhere. These are grown largely by subsistence farmers in a tropical climate, and continuous planting and sequential harvesting (section 6.1.2) often allows a supply of freshly harvested roots throughout the year. In this situation long-term storage is not required. In other cases, during the dry season, tubers need to be stored either in the field or in small storage structures (Data et al. 1987). Second, there are the yellow-fleshed, sweeter varieties grown as annual crops in more temperate climates such as in the USA and used as a dessert. The latter may need to be stored for more than 6 months until the next season, to supply food demands and also 'seed' for the next season (Moyer 1982).

After harvest, surface wounds may be healed by reactions within the tuber called 'curing,' which are expedited by exposing it to about 30 °C at 85–90% relative humidity (RH) for about 7 days (Hamann et al. 1980; Uritani et al. 1984). This healing of wounds reduces the onset of diseases which are a major source of postharvest losses (Moyer 1982; Hammett et al. 1982a). Curing also reduces weight loss of stored tubers due to biological processes such as respiration, transpiration and sprouting (Booth 1974; Winarno 1982). Storage is facilitated by temperatures of 10–15 °C and 85–90% RH, but temperatures lower than 8 °C may cause chilling injuries (Uritani et al. 1984; Hong 1982). Optimal storage may be achieved in temperate climate winters such as in Japan, but in tropical and subtropical regions the higher ambient temperatures promote sprouting during storage, and hasten damage from fungal infection and insect infestation (Uritani et al. 1984). In Bangladesh, losses of 20–25% occur when tubers are stored for 2–4 months in shallow piles on the earthen floors of farmers' houses at 24–35 °C and 70–90% RH (Jenkins 1982). In the Philippines sweet potato tubers have been stored for up to 3 months in ventilated village storage structures in which the relative humidity may be controlled at ambient temperatures (Data et al. 1987).

During storage for 4 months at 8–10 °C and 80–85% RH there was a decrease in moisture from 72 to 69%, a 13% decrease in starch, 26% decrease in protein, 41% decrease in vitamin C and a 12% increase in sugar (Sharfuddin and Voican 1984). An increase in sugar content and an improvement in flavour was brought about by curing (Hamann et al. 1980) and also by storage (El-Tamzini 1976). Tubers stored at 13 °C for up to 281 days showed some small changes in amino acid composition and in the non-protein nitrogen fraction (Purcell and Walter 1980). Loss of β-carotene occurred

during storage of sweet potatoes at 10°C and 75% RH for 10 weeks (Charoenpong 1984). An 18% loss of β-carotene and 49% loss of vitamin C occurred over 4 months' storage at 24°C (Ranganath and Dubash 1981). We have observed losses of 3, 16 and 17% of total vitamin C (ascorbic acid + dehydroascorbic acid) with sweet potato samples stored for 28 days at 0, 15 and 25°C, respectively (Bradbury and Singh 1986a). Clearly, significant changes of composition occur on storage. It would be useful to know the extent of these changes in a systematic study in which all nutrients were monitored over an extended period of time for different storage temperatures.

4.6.2 Storage of Taro *Colocasia* and *Xanthosoma*

Less is known about the storage of these crops compared with sweet potato, yams or cassava. Both taro *Colocasia* and *Xanthosoma* may be harvested as required after 6 months and field stored for many months, and in extreme circumstances up to 2-3 years (Onwueme 1978; Parkinson 1984b). In the South Pacific taro is stored in pits lined with coconut fibre or plantain leaves, which are covered with the same material and then sealed with a layer of soil. Unpeeled corms will remain edible for 2-3 months and peeled corms for 1 month (Parkinson 1984b). By contrast, studies in Trinidad showed that *Colocasia* did not store satisfactorily for more than 2 weeks in tropical conditions irrespective of storage treatment, but *Xanthosoma* could be stored for 6 weeks (Passam 1982). Perhaps the traditional storage methods used in the South Pacific are superior to those used by Passam (1982), who found that the respiratory activity of the corms is high. Weight losses of more than 30% in 6 weeks due mainly to loss of moisture may be prevented by packing in moist coir or by using polyethylene bags. Losses also occur when corms sprout at high relative humidity and when rot develops (Burton 1970; Passam 1982). Curing of *Colocasia* and *Xanthosoma* corms at 35°C and 95% RH for 5 days resulted in reduced weight loss and sprouting, but did not reduce rotting in *Colocasia* (Passam 1982). Reduction of storage temperature increases the time of safe storage. Thus at the optimum temperature of 7°C and 85% RH, *Colocasia* did not deteriorate over 3.5 months (Passam 1982).

Because of the importance of taro *Colocasia* and *Xanthosoma* as world food crops (sections 1.1.2 and 1.1.3), and the appreciable amount shipped in the South Pacific region, further work is required on storage. Furthermore, we have been unable to find any data on changes in nutrient content in taro *Colocasia* or *Xanthosoma* on storage and point to the need for work in this field.

4.6.3 Storage of Giant Taro, *A. macrorrhiza*, and Giant Swamp Taro, *C. chamissonis*

Both giant taro and giant swamp taro are perennials planted independently of season and harvested from about 9 months to 4 years or more (sections 1.1.4 and 1.1.5), hence the corms are usually not stored (Sakai 1983). In the South Pacific, however, giant taro may be stored in barns also used to store yams. Giant swamp taro may be stored by submerging corms in water or covering them with wet sand. Storage in lined pits covered with soil or stones, using the methods described above for taro, allows storage of giant swamp taro for 2-3 months (Parkinson 1984b). It is our experience that giant taro and giant swamp taro may be stored in air for about 1 month at 15°C. The recommended storage temperature for giant taro is 5°C (Sakai 1983). No storage trials have been reported on giant swamp taro (Sakai 1983) and there do not appear to have been any studies on changes in nutrients on storage of either crop.

4.6.4 Storage of Yams

Yams are a tropical annual crop and the tubers become dormant soon after harvest. Their respiration rate is greatly decreased during dormancy, and in the

absence of physical damage or pathological attack they may be normally stored for periods of 3–6 months until sprouting occurs (Passam and Noon 1977; Ikediobi and Oti 1983; Mozie 1984). The onset of sprouting may be reduced by storing below 20 °C, but tubers exposed to temperatures below 13 °C may suffer chilling injury (Noon 1978). In a study by Passam et al. (1982), following the breakage of dormancy sprouts were excised and yam *D. alata* tubers were, in this case stored for 40 weeks at ambient temperatures, wrapped in paper or buried in dry coir dust. The fresh weight dropped by 60% but the viability of the tubers was maintained.

The physical damage of tubers that occurs during harvesting and handling may be reduced by curing the tubers at 35 °C and high relative humidity for some days (Passam et al. 1976). Curing reduces the likelihood of pathological attack by microorganisms which is the major source of loss during storage of yam (Noon 1978; Onwueme 1978). Postharvest deterioration of tubers may also be caused by attacks by pests, sprouting, respiration and transpiration or dehydration (loss of water from the tuber). Respiration and transpiration can cause up to 25% loss of edible material during storage (Coursey 1983b), but there is relatively little change in the nutritional value of the material remaining after respiration losses (Gonzalez and Collazo de Rivera 1972). Ikediobi and Oti (1983) showed that the content of various enzymes, ascorbic acid, carotenoids and lipids increased during storage and peaked at sprouting. The content of sugars also increased near the end of the dormant phase (Coursey 1983b). Clearly, as with sweet potato and taro, a systematic study is needed of all nutrient changes that occur during storage of yams.

4.6.5 Storage of Cassava

The swollen roots of cassava do not possess bud primordia and are not capable of acting as organs of propagation. They act simply as carbohydrate stores that may be used by the plant, enabling it to survive during periods of drought (Passam and Noon 1977). Unlike yam tubers, they have no endogenous period of dormancy. Cassava tubers are more perishable than any of the other major root crops, temperate or tropical, and deteriorate extremely rapidly after being detached from the plant (Rickard and Coursey 1981). The deterioration in air at ambient temperatures usually occurs in 3–4 days.

The primary deterioration is an endogenous physiological process called vascular streaking which results in a fine blue-black or brown discoloration. It is followed by secondary deterioration which involves microbial rotting or sometimes softening or fermentation of the tissue (Rickard and Coursey 1981; Hirose and Data 1984). The physiology and biochemistry of the primary deterioration has been studied in some detail and involves increased activity of various enzymes, production of catechin and coumarin components including scopoletin, scopolin and esculin and of other metabolites (Uritani et al. 1984; Rickard 1985; Sakai et al. 1986). Mechanical damage to the root during and after harvesting is significant in causing primary deterioration and in facilitating secondary deterioration. This may be reduced by the process of curing which involves exposure of the tubers to about 35 °C at 80–85% RH.

There are various methods by which it is possible to improve the storage properties of cassava. As already indicated for other crops and for cassava (section 1.1.8), an appropriate procedure particularly in subsistence agriculture is to leave them in the ground until needed. Pruning all the branches from the plants up to 3 weeks before harvest causes changes to occur in the tuber which improves storage (Rickard and Coursey 1981; Odigboh 1983). Longer periods of storage up to 2 months may be obtained by reducing the exposure of roots to air and by reducing moisture loss by packing them in moist sawdust in boxes (Booth et al. 1976; Sivan 1979) and by other means such as storage in clamps or interlayered between cassava leaves or coating

tubers with wax. Cold storage at 3 °C is optimal. Samples stored in the deep freeze at −20 °C appear stable for long periods, although we have observed that over 6–8 months storage bound cyanide (linamarin) is broken down and appears as free cyanide (section 3.7).

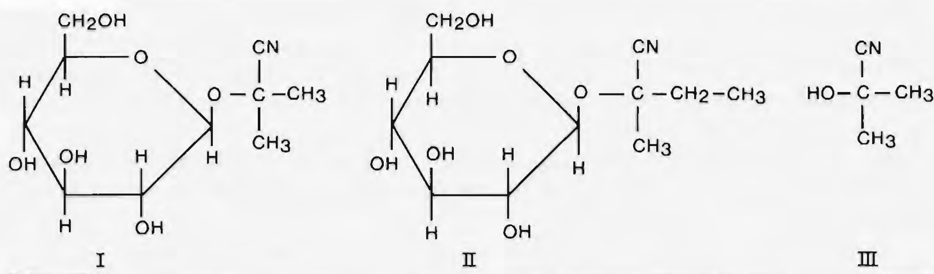
Booth et al. (1976) have studied changes that occur in the composition of cassava roots on storage in moist sawdust and in clamps, a traditional procedure where the freshly harvested tubers are placed on a bed of straw on dry ground and covered with straw and a layer of soil taken from around the clamp. They observed a rapid conversion of starch to sugars such that the sugar content was two to three times its original level after 2 weeks of storage. This was accompanied by softening of the central part of the tuber. Pillai et al. (1970) observed an increase in sugar and decrease in starch on storage of tubers in soil. Kawabata et al. (1984) found an increase in the amounts of glucose and fructose and a decrease in the amount of sucrose during storage at ambient temperature. Physiological deterioration caused a reduction in the β-carotene content of golden yellow cassava (Gloria and Uritani 1984). More research work is needed on these and other changes in composition which affect human nutrition of cassava tubers during storage (Rickard and Coursey 1981).

Chapter 5. Antinutritional Factors in Root Crops

There are a number of chemicals present in root crops that are either potentially toxic or which may reduce the bioavailability of other nutrients. Four problems will be considered here. These are: (i) cyanide in cassava, (ii) trypsin and chymotrypsin inhibitors, (iii) calcium oxalate and oxalates, and (iv) acridity of aroids. Other problems of this type exist as seen by reference to the literature (National Academy of Science 1973; Liener and Kakade 1980), but the four issues to be considered here are of particular importance in the context of the ACIAR/ANU Program on Nutrition of Tropical Root Crops in the South Pacific.

5.1 Cyanide in Cassava

Cyanide occurs in cassava in two closely related cyanogenic glucosides linamarin (I) and lotaustralin (II) in relative amounts of about 93 and 7% respectively (Okigbo 1980; see also sections 1.1.8 and 3.7). These chemicals are produced in the plant from valine and isoleucine respectively (Conn 1981).



The extracellular enzyme linamarase present in cassava gains access to the cyanogenic glucosides I and II after physical disruption of the cell, whence it catalyses their hydrolysis to glucose and the corresponding cyanohydrin (Montgomery 1980). The cyanohydrin from linamarin (III) breaks down rapidly to give HCN and acetone (CH_3COCH_3) in alkaline solution at ambient temperature, but under slightly acid conditions (pH 6) only 50% had broken down in 30 min (Cooke 1978).

The cyanide present in cassava may therefore be considered to be of two types: (1) bound cyanide present as the cyanogenic glucosides (I and II), and (2) free cyanide present as the cyanohydrin, as free HCN which is a gas above 26°C and (under alkaline conditions) as CN^- (Cooke and Coursey 1981). It is important to distinguish

between bound and free cyanide present in cassava, because as is shown below, it is much easier to remove free cyanide from cassava by cooking and other methods of processing than bound cyanide. As discussed in section 2.26, we determined the total cyanide (free + bound) by phosphoric acid extraction of cassava, hydrolysis of the cyanogenic glucoside with linamarase, rapid dissociation of the cyanohydrin in alkaline solution and colorimetric determination of cyanide. Free cyanide was determined in a similar manner but without the use of linamarase.

Cyanide is widely distributed in nature and is a normal constituent of blood, usually at low concentrations $< 12\ \mu mol/l$ (Solomonson 1981). It has been suggested that at least some of the cyanide present in the body comes from defence processes continuously occurring in tissues (Stelmaszynska and Zgliczynski 1981). It is much better known that cyanide of higher concentrations rapidly causes death. The lethal dose range for humans of HCN taken by mouth is 0.5–3.5 mg/kg body weight, which for a 60-kg adult amounts to 30–210 mg of HCN (Montgomery 1980; Solomonson 1981). The lethal action of cyanide involves blocking the reduction of oxygen in the respiratory pathway (Lehninger 1982).

How does the body metabolise ingested cyanide? There are several possible detoxification mechanisms (Montgomery 1980), one of which involves reaction of cyanide with a group of related compounds called sulfanes. This reaction is catalysed by the enzyme rhodanese and produces thiocyanate (SCN^-) (Westley 1981). The concentration of thiocyanate in the blood is about one thousand times that of cyanide, and the former may be filtered out rather slowly by the kidneys (Westley 1981). The thiocyanate can, however, also react further with hydrogen peroxide, catalysed by peroxidases, to give sulfate and re-form cyanide.

The sulfur, which is used in the detoxification of cyanide to produce thiocyanate, comes from the essential S-containing amino acids, methionine and cystine. It has been proposed that this could lead to depletion of these essential amino acids, particularly in cases in which protein-energy malnutrition also occurs (Montgomery 1980; Delange 1983). However, it was found that in areas of Zaire in which there was considerable cassava consumption and also protein-energy malnutrition, the serum levels of methionine were no lower than in control regions such as Brussels (Vis et al. 1982). The absence of any effect on serum levels is probably due to the fact that the safe daily intake of S-containing amino acids that we have calculated for a 50-kg adult (FAO/WHO/UNU 1985) provides nearly thirty times as much sulfur as that needed to maintain the maximum level of daily urinary excretion of 10.8 mg of SCN^- due to cassava consumption (Hennart et al. 1982). Thus the amount of sulfur needed to detoxify ingested cyanide from cassava is very small compared with the daily intake of sulfur-containing amino acids, and cannot therefore affect levels of protein-energy malnutrition.

A deficiency of iodine in the diet causes the development of goitre. Iodine is absorbed from food and taken up by the thyroid gland with formation of the hormones triiodothyroxine and thyroxine. The accumulation of iodine in the thyroid gland is inhibited by a group of 'ionic inhibitors' which includes SCN^- and perchlorate. For example, in a study with rats, perchlorate was found to be ten times more effective as an inhibitor than SCN^- (Goodman and Gilman 1985). The mechanism of the action was observed on rats using radioactive tracers and indicated that in the presence of SCN^- there was an accelerated discharge of iodine from the thyroid gland (Ermans et al. 1983). Excessive levels of SCN (SCN overload) may therefore lead to reduced iodine uptake, which in an iodine-deficient region may contribute to endemic goitre and endemic cretinism (stunted growth with mental deficiency and deficient hearing and speech). Under normal conditions the ratio of I/SCN (μg I/mg SCN) in the urine is >7. Endemic goitre develops if this ratio falls below a critical

value of about 3. If the ratio falls below 2, endemic goitre is further complicated by the occurrence of endemic cretinism and mental retardation (Delange et al. 1983). This has occurred in some parts of Zaire due to severe iodine deficiency, coupled with the utilisation of poorly detoxified cassava. Pregnant women and new-born babies are especially at risk in a goitrogenic environment.

If the iodine supply is greater than about 60 μ/day, goitre is not abnormally prevalent even in the presence of a high SCN^- supply, because the I/SCN ratio is >7. This accounts for the absence of goitre in many populations in which cassava constitutes a staple food. However, the massive introduction of cassava because of food shortage to populations previously adapted to iodine deficiency without any abnormal prevalence of goitre, results in the development of endemic goitre in these populations (Delange et al. 1983). Evaluation of the goitrogenic environment in a given area should be based on the simultaneous assessment of the degree of iodine deficiency and the SCN^- overload.

Endemic goitre and cretinism may be prevented by an increase in the intake of iodide and, if the I/SCN ratio is <7, by decreased intake of cyanide from cassava. Increased intake of iodide by use of iodised salt has little chance of success in regions where salt intake is small or variable, but the alternatives are systematic administration by injection of iodised oil which has given effective protection for 3–5 years (Ermans et al. 1983) or iodised oil given by mouth, which is cheaper and gives protection for 1–2 years (Hetzel 1984). Decreased intake of cyanide from cassava may cause relief of endemic goitre and cretinism and would prevent other diseases related to cyanide intake, including tropical ataxic neuropathy, blindness (Montgomery 1980), tropical calcifying pancreatitis and pancreatic diabetes (Geevarghese 1983). Reduced cyanide intake could be achieved by: (1) reducing the cyanide content of cassava by breeding; (2) improving detoxification processes used during the preparation of cassava-based foods; and (3) reducing the frequency and quantity of consumption of such food. We will now consider the first two matters in more detail.

5.1.1 Selection/Breeding of Cyanide-Free Cassava

At the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, breeding for low cyanide has been in progress since 1973, but a zero-cyanide cassava has not yet been located. Low cyanide (5–10 mg/100 g) cultivars resistant to disease and relatively high yielding (15–25 t/ha) have been developed (Hahn and Keyser 1985). Cassava with cyanide-free tubers was reported from Indonesia before World War II but was subsequently lost, and other cultivars from there contained 0.6 mg/100g (de Bruijn 1983). In Zaire, cultivars were reported with levels of 0.2 and 0.5 mg/100 g (Bourdoux et al. 1982). At the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia, no zero-cyanide cultivars were found in their germplasm bank (de Bruijn 1983). Whether a completely cyanide-free cassava tuber will ever be obtained is an open question, since cyanide is considered to give the plant a biological advantage by offering a defence against insects (Montgomery 1980).

It seems to be now generally agreed that breeding cassava for low cyanide and high yield should be possible (Cooke et al. 1978; de Bruijn 1983). The 20 representative cultivars from Solomon Islands, Fiji and Papua New Guinea that we have analysed (Appendix Tables A.49–A.51) showed generally low levels of cyanide (1.3–6.3 mg/100 g total cyanide) and gave acceptable yields (13–35 t/ha), confirming that high yielding cultivars may have low cyanide. Of the 80 tubers analysed, one tuber of cv L12 from PNG gave 0.7 mg/100 g and two other tubers of cv L19 (PNG) and New Guinea (Fiji) gave <1 mg/100 g (section 3.7). These low results for cyanide obtained from this small survey in the South Pacific and the reportedly low values from

Indonesia, would give encouragement to the screening for acyanogenesis of the 150 accessions from the South Pacific (section 1.1.8) and the 600 accessions from Indonesia (Soenarjo, R., pers. comm.). It should be noted that there is up to ten times more linamarin near the skin than at the centre of the tuber (section 3.9), and that the cyanide content of edible leaves is about the same as that of the tuber (section 3.7).

5.1.2 Postharvest Processing (Including Cooking) of Cassava to Reduce Cyanide

There are many traditional methods that have been used for the preparation of cassava products such as gari, fufu, fuku, chickwangue, ntuka, moteke in Central and West Africa (Bourdoux et al. 1982; Oke 1983) and other products in other places (Onwueme 1978). All these processes involve combinations of maceration, soaking, boiling, drying and fermentation of the tubers (Coursey 1973; Cooke and Coursey 1981; Cooke 1983). Variable results were reported by different workers for removal of cyanide by these methods, which were undoubtedly due to differences between analytical methods, as well as the wide variations between treatment methods of different workers (Cooke and Coursey 1981).

There are still great differences between results of different workers on the efficacy of air-drying of samples. Air-drying of cassava chips at 47–60 °C effectively removed free cyanide, but retention of bound cyanide was about 70% after 20 hours (Cooke and Coursey 1981), whereas sun-drying and oven-drying of chips removes about 80% of free cyanide and 80–98% of bound cyanide (Gomez and Valdivieso 1985). Other studies have shown a retention of about 30–60% of bound cyanide due to sun-drying, and if the tuber was crushed before sun-drying, retention was further reduced to less than 5% (Nambisan and Sundaresan 1985). Another report by Bourdoux et al. (1982) claimed that sun-drying alone produced the food with the highest cyanide content. Long soaking of cassava tubers in water (retting) caused some loss of soluble proteins (Bourdoux et al. 1982) and starch, but followed by sun-drying, removed up to 98.6% of the cyanide and was twenty times more efficient in cyanide removal than simple sun-drying (Ayernor 1985). Prolonged soaking in water of cassava tubers followed by cooking was also found to be much superior to drying by Bourdoux et al. (1982, 1983).

Most workers have found methods that utilise soaking in water to be superior to drying methods. This is due to the fact that the free cyanide (HCN and cyanohydrin), and the bound cyanide (glucoside), are both water-soluble and hence may be leached out. Furthermore, the endogenous linamarase catalyses the hydrolysis of the glucoside. Sun-drying and boiling or steaming remove free cyanide, but probably denature linamarase and hence the bound cyanide is not broken down.

Fermentation of cassava, widely used to produce gari in West Africa, causes breakdown of bound cyanide by microorganisms and linamarase and also production of organic acids. The free cyanide (cyanohydrin), however, is quite stable in the acid solution, hence the residual cyanide level may be appreciable unless the sample is well washed (Cooke and Coursey 1981; Nartey 1981; Oke 1983; Ejiofor and Okafor 1984). It should be noted that cross-sections of cassava tuber stored for 3 days at ambient temperature showed a large increase in the total cyanide content, particularly of inner tissue, hence wounded cassava roots are not recommended for human consumption because of expected increased levels of cyanide (Kojima et al. 1983).

5.1.3 South Pacific Situation

The minimum and maximum levels of HCN recorded from a single tuber in our survey of 20 cultivars from Papua New Guinea, Solomon Islands and Fiji was

0.7–9 mg/100 g fresh tuber. There were no significant differences between the cyanide content of cultivars from the three different countries. Taking the worst case (9 mg/100 g), and assuming 50% removal of cyanide on cooking, we would be left with 4.5 mg/100 g. The lethal dose for a 60-kg adult is 30–210 mg HCN (section 5.1), and would be reached by consumption of 0.66–4.7 kg of cooked cassava. The amount at the lower end of the range may reasonably be expected to be consumed in a single meal. The average situation (about 3 mg/100 g) reduced by 50% on cooking leads to a consumption level of three times that of the worst case, viz. 2–14 kg of cooked cassava. The fact that the consumption of cassava from cultivars considered to be dangerously poisonous (10–100 mg/100 g fresh weight) is rarely lethal (Cooke and Coursey 1981), may be partly due to the small amount that is present as HCN, some as cyanohydrin (which is stable under acid conditions) and the remainder as linamarin, which requires the presence of linamarase for rapid hydrolysis (Cooke 1978; Nahrstedt 1981). Because of a shortfall of iodine in parts of the Highlands of Papua New Guinea, there is some incidence of endemic goitre, but no appreciable consumption of cassava; sweet potato is the staple food (Alpers, M., and Hide, R. pers. comm.).

5.2 Trypsin and Chymotrypsin Inhibitors

Enzyme inhibitors are widely distributed in plant and animal tissues and there is a very extensive literature including a number of reviews on the subject (Whitaker and Feeney 1973; Ryan 1973; Richardson 1977; Liener and Kakade 1980; Laskowski and Kato 1980; Ryan 1981). Listings by Whitaker and Feeney (1973) and Liener and Kakade (1980) show not only the breadth of the distribution of inhibitors in animals and plants, but also the large number of enzymes for which inhibitors have been found. There is a wide range of proteinase inhibitors, of which trypsin inhibitor is most widely studied, and there are also amylase, invertase, peroxidase and catalase inhibitors (Whitaker and Feeney 1973). For example, in potato, *Solanum tuberosum*, proteinase inhibitors account for 15–25% of the soluble proteins of the tuber, and 13 different species of inhibitors have been observed which inhibit the serine proteinases (trypsin, chymotrypsin, etc.), carboxypeptidase, papain, microbial proteinases and kallikreins (Liener and Kakade 1980).

5.2.1 Physiological Role in the Plant

There are three possible roles that have been proposed to explain the presence of proteinase inhibitors in plants, which are not necessarily mutually exclusive. They are: (1) storage of protein; (2) regulation of proteinases; and (3) plant protection against attack by invading organisms. Two important questions are the intracellular localisation of the inhibitors within the plant, and the presence of inhibitors in the various tissues at different stages of development of the plant. It is not easy to generalise on either of these matters (Richardson 1977).

The possibility that inhibitors have a role as storage proteins may be supported by the fact that they make up about 6% of the protein in soybean, up to 10% of the soluble protein in barley grains (Ryan 1973) and 15–25% in potato (Liener and Kakade 1980). However, these levels are not very high, particularly compared to that of giant taro (viz. 67%, section 5.2.5). The behaviour of a single chymotrypsin inhibitor was followed through the life cycle of potato plants and it behaved as if it were a storage protein (Ryan 1973).

With several plants it has been shown that inhibitors that are active against endogenous proteinases within the plant disappear during germination. This suggests that these inhibitors play a role in regulation of the action of proteinases within the

plant. Although in certain cases this is an attractive hypothesis, there are several arguments against it being generally applicable (Liener and Kakade 1980).

The most likely postulate appears to be that inhibitors are allelochemicals, i.e. chemicals present in the plant which are a defence mechanism against the onslaught of organisms (Waller 1987). In work summarised by Ryan (1973), the digestive proteinases of several insects have been obtained and found to be inhibited by proteinase inhibitors from plant sources. The presence in food (seed, leaves) of proteinase inhibitors, to the extent of 5–10% of the soluble proteins, might be expected to have a significant effect on the feeding of plant-eating insects. Furthermore, it has been found that after an attack by insects or mechanical wounding, many plant leaves accumulate proteinase inhibitors at the site of damage and also in adjacent tissues (Ryan 1973, 1981; Liener and Kakade 1980). Proteinase inhibitor genes were also induced by wounding and were transferred from potato to tobacco plants (Sanchez-Serrano et al. 1987). It was postulated that a proteinase inhibitor-inducing factor was released from damaged leaves and for tomato leaves this was shown to be a polysaccharide (Bishop et al. 1984).

5.2.2 Types of Inhibitor and Their Mode of Action

Enzyme inhibitors normally make a strong attachment at the active site of the enzyme, thus preventing the approach of substrate to the active site and effectively inactivating the enzyme. This mode of action has been shown clearly by studies on the proteinase inhibitors of soybean *(Glycine max)* which, broadly speaking, fall into two groups as follows: (1) Kunitz inhibitor of molecular weight about 20 000, which inhibits trypsin on a 1:1 basis (Kunitz 1947); and (2) Bowman-Birk inhibitor of molecular weight about 8000, which inhibits trypsin at one site and chymotrypsin at another site on the same molecule (i.e. it is 'double headed').

The sequence of amino acids along the protein chain has been determined for both the Kunitz inhibitor of 181 residues from soybean and the Bowman-Birk inhibitor of 71 residues. Furthermore, the three-dimensional structure of the Kunitz inhibitor–trypsin complex was determined from X-ray crystallographic studies (Blow et al. 1974; Janin et al. 1974; Sweet et al. 1974). The site of interaction of the inhibitor involves about 10 of the 181 residues, which make non-covalent bonds with the active site region of trypsin and strongly bind the two molecules together. The recognition site of the inhibitor is the residues Arg 63 and Ileu 64. Arginine 63 forms a covalent bond with the active site serine of trypsin, but this is, however, not essential for the stability of the complex.

5.2.3 Molecular Structure of Inhibitors in Root Crops

Many of the trypsin and chymotrypsin inhibitors present in legumes, cereals and some root crops fall into one of the two groups of inhibitors already described for soybean, but there are others which are neither Kunitz nor Bowman-Birk inhibitors (Laskowski and Kato 1980). For example, there are at least three inhibitors from sweet potato which are probably of the Kunitz type. Two of these have molecular weights of about 23 000, inhibit trypsin but not chymotrypsin and also show weak inhibition of the enzymes plasmin and kallikrein (Sugiura et al. 1973; Ogiso et al. 1974).

The proteinase inhibitors from the aroids have also been studied. Sumathi and Pattabiraman (1979) found a trypsin inhibitor from *Colocasia esculenta* var. *antiquorum*, which had a molecular weight of 40 000 and also weakly inhibited chymotrypsin. Subsequent work showed that the molecule was a dimer (Ogata and Makisomi 1984, 1985). Our studies on taro (*Colocasia esculenta* var. *esculenta*) (section 1.1.2) have shown that it contains a trypsin inhibitor with a dimer molecular weight of

43 600, which does not inhibit chymotrypsin (Hammer 1987). There is also a related trypsin inhibitor present in giant taro (*A. macrorrhiza*) (Sumathi and Pattabiraman 1977), which is also active as the dimer of molecular weight 39 000 and which strongly inhibits chymotrypsin (Hammer 1987). A complete sequence determination on this trypsin–chymotrypsin inhibitor showed: (1) that the dimer consisted of two identical molecules (monomers); (2) that the recognition site of the inhibitor involves phenylalanine rather than an arginine residue; and (3) that there was some similarity of the sequence (sequence homology) with that of the Kunitz inhibitor from soybean (Argall 1987). A similar trypsin inhibitor of dimer molecular weight 43 600, which did not inhibit chymotrypsin, was found in giant swamp taro (*C. chamissonis*) (Hammer 1987). The first 10 amino acid residues from the amino-terminal end of the protein have similar sequences for the trypsin inhibitors from taro, giant taro, giant swamp taro and the Kunitz inhibitor from soybean (Hammer 1987).

5.2.4 Inhibitor Content and Distribution in Tubers and Corms

The amounts of trypsin and chymotrypsin inhibitors present in the various root crops are summarised in Table 3.15 and by Bradbury and Hammer (1988). The amount in giant taro is very large and as a percentage of the total crude protein present (19–60%) greatly exceeds that from other plants such as potato *Solanum* (10%), barley (7.5%) and legumes (6%). It is about twenty times the amount present in sweet potato and taro *Colocasia*, which is five times as much as in giant swamp taro. There are very small amounts present in taro *Xanthosoma* and yam (*D. alata*), whereas Sumathi and Pattabiraman (1975) reported its absence from the latter. On the other hand, they found a small amount of trypsin and chymotrypsin inhibitor in cassava, whereas we found none in nine cultivars of cassava (Appendix Table A.49).

Since the same inhibitor molecule from giant taro inhibits both trypsin and chymotrypsin, there is a high level of chymotrypsin inhibition by giant taro. This level equals or exceeds that found in other rich sources of chymotrypsin inhibitor such as navy bean, French bean, winged bean and peas (Hammer 1987). A small amount of chymotrypsin inhibitor was present in sweet potato from Solomon Islands (Appendix Table A.1) but none was present in cultivars from the Southern Highlands of Papua New Guinea (Bradbury et al. 1985b). Chymotrypsin inhibitor was not present in taro *Colocasia* or *Xanthosoma*, giant swamp taro or in yam, *D. esculenta*.

The concentration of the trypsin/chymotrypsin inhibitor of the cigar-shaped giant taro corm decreased approximately linearly from the centre to a near zero value just beneath the skin. There was no longitudinal gradient of concentration. By comparison there was no radial gradient of concentration of trypsin inhibitors in taro *Colocasia* or giant swamp taro, but a decrease in inhibitor concentration towards the bottom (distal) end of the corm (Hammer 1987; Bradbury and Hammer 1988).

5.2.5 Stability of Trypsin Inhibitor to Heat and on Cooking

The results of these studies are conveniently considered separately for sweet potato and for the aroids taro *Colocasia*, giant taro and giant swamp taro.

Sweet Potato The purified inhibitors were found to be stable in buffer solution at pH 8 at 70 °C and partially denatured at 90 °C after 30 min heating (Sugiura et al. 1973). A more detailed study showed that the different trypsin inhibitors present had different heat stabilities (Dickey and Collins 1984). Our experiments were designed to simulate much more closely actual cooking procedures. Also, because of the large variability of trypsin inhibitor content between different tubers (Bradbury et al. 1984a, 1985b), the tubers were cut longitudinally into four quarters. One segment was used as

a control and the others were subjected to: (1) heating in an oven at a fixed temperature (60, 70, 80, 90 or 100 °C) for 2 hours; (2) baking at 150 °C in an oven for 15, 30 or 50 min; and (3) heating in boiling water for 15, 20 or 30 min. In experiments (1) and (2) but not (3) the samples were wrapped tightly in aluminium foil. The weight of the samples was ascertained before and after heating, and the trypsin inhibitor contents determined by the diffusion assay method (section 2.24.1). A small thermistor embedded in the sweet potato showed that in experiment (1) the centre of the specimen achieved the temperature of the oven in 100 min, and in experiments (2) and (3), the temperatures at the centre of the specimens had reached about 85 °C after 30 min (ACIAR/ANU Program 1984; Bradbury et al. 1988b). In experiments (2) and (3) the sweet potato specimens were edible after 25 min and 15–20 min respectively.

The results of experiment (1) showed that for five different cultivars from Solomon Islands the trypsin inhibitor was completely denatured at 100 °C and 0–70% of residual activity remained at 90 °C, in reasonable agreement with Sugiura et al. (1973). Baking at 150 °C (experiment 2) caused a steady fall in activity with time for seven cultivars from Solomon Islands and Papua New Guinea. After 30 min there was zero activity in six cultivars and there remained about 5% activity in one cultivar. This showed that baking until the samples were cooked essentially inactivated the trypsin inhibitor. Boiling of four sweet potato cultivars from Tonga and Solomon Islands (experiment 3) showed that the trypsin inhibitor content was reduced to zero after 15 min.

Taro Colocasia, Giant Taro and Giant Swamp Taro Two cultivars of taro *Colocasia* from Solomon Islands, three cultivars of giant taro from Western Samoa and one cultivar of giant swamp taro from Fiji were heated in boiling water (see experiment (3) above). The inhibitor activity increased with time of heating for 5–10 min (in contrast to the decline noted for sweet potato) and was similar to that observed by Sumathi and Pattabiraman (1979) for *Colocasia esculenta* var. *antiquorum*. With taro and giant swamp taro the inhibitor activity was, in some cases, initially almost zero and increased by a factor of 2–10 times, passed through a maximum and fell to zero in 20 min. With giant taro the maximum activity was 700–1000 TIU/g and there was still appreciable activity left after boiling for 20 min, but zero activity after 30 min (Hammer 1987; Bradbury et al. 1988b). All samples were cooked after 20 min, by which time there was no activity left in the taro and giant swamp taro, but there was still some activity (20–400 TIU/g) remaining in the giant taro samples (Hammer 1987).

The results of an experiment in which uniform, thin slices of giant taro were heated in an oven at a fixed temperature for 2 hours, are shown in Fig. 5.1. The reason for the progressive drop in inhibitor activity on heating for 2 hours at temperatures of 40 and 50 °C is not clear. The increase in activity shown in Fig. 5.1 on heating for 2 hours at 60–80 °C is the heat activation effect noted above. It was not observed when an aqueous solution of the inhibitor was heated using the same range of temperatures and times used for the intact tissue of giant taro (Hammer 1987; Bradbury et al. 1988b). In this case, heating always led to a reduction in inhibitor concentration. This showed that the process was not due to rearrangement of the structure of the protein molecule, but involved the location of the inhibitor within the corm tissue. Hammer (1987) found that the giant taro tissue changed from a crisp to a rubbery consistency on heating, at about the time that the inhibitor concentration was maximal. He proposed that this change of state of the tissue may have been due to disintegration of cell walls (such as occurred with the aleurone cell walls of rice grains on heating below 100 °C—Bradbury et al. 1984b), which resulted in the large increase in inhibitor activity (Hammer 1987).

Above 80 °C the activity shown in Table 5.1 decreased rapidly with increase of temperature, due to the onset of heat denaturation of the giant taro trypsin inhibitor.

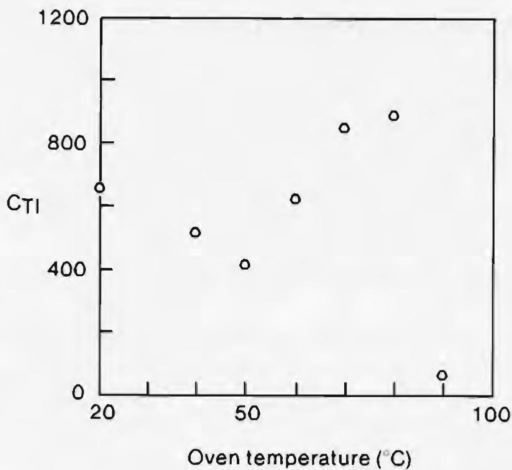


Fig. 5.1 Graph of trypsin inhibitor activity C_{TI} (TIU/g) of thin, uniform slices of giant taro which had been heated in an oven at a fixed temperature for 2 hours, against the temperature of the oven (after Hammer 1987).

Its stability towards heat denaturation in dilute aqueous solution was found to be greater using a sample of purified inhibitor, than with a crude extract (Sumathi and Pattabiraman 1977; Hammer 1987; Bradbury et al. 1988b). It is probable that other constituents of the crude extract may be involved in deactivation of the trypsin inhibitor.

5.2.6 Implications for Nutrition of Trypsin and Chymotrypsin Inhibitors

The presence of trypsin inhibitor in uncooked animal feed has long been known to cause diminished growth in rats, chickens and other experimental animals. The literature on this subject, which has been reviewed by Liener and Kakade (1980), is difficult and contains many inconsistencies. With the tropical root crops, it is clear that the very high concentration of trypsin and chymotrypsin inhibitor present in uncooked giant taro corms would be very deleterious to animal nutrition. Since 20–60% of the total protein of giant taro corms occurs as a molecule which inhibits the two major proteinases (trypsin and chymotrypsin) of the small intestine, it is unlikely that the animal would be able to break down much protein to amino acids. The levels of trypsin inhibitor present in sweet potato, taro *Colocasia* and giant swamp taro would also probably be sufficient to slow the growth of pigs and other animals (Bradbury et al. 1988b). It is not known whether the silage treatment of taro leaves and other aroid residues, which removes acridity (section 5.4) and makes the material palatable for animals, also breaks down trypsin inhibitor.

We are more concerned with human nutrition. Boiling or baking for sufficient time to make the tuber or corm soft enough to eat has been shown in section 5.2.5 to inactivate virtually all the trypsin inhibitor present in sweet potato, taro *Colocasia* and giant swamp taro. With giant taro, however, an appreciable amount of inhibitor was still active and an additional 10 min boiling was required to inactivate all inhibitors. We conclude that giant taro should be well cooked before eating, in order to inactivate all inhibitors (Bradbury et al. 1988b). Sakai (1983) indicates that *prolonged* cooking has been widely practiced in the South Pacific region, and our study shows a very good reason why this practice is a good one. It also assists in the removal of the acridity of the corm, discussed in section 5.4.

5.3 Calcium Oxalate and Soluble Oxalate

Oxalates occur in nearly all forms of living matter. In plants they may be present as the soluble salts, potassium, sodium or ammonium oxalate, as oxalic acid or as insoluble calcium oxalate. Certain plant foods contain appreciable amounts of oxalate: spinach, 0.3–1.2%; rhubarb, 0.2–1.3%: beet leaves, 0.3–0.9%; tea, 0.3–2.0% and cocoa, 0.5–0.9%. Most vegetables and fruit commonly used in temperate climates contain about one-tenth of these amounts (Fassett 1973). In any particular plant the leaves usually contain more oxalate than the petiole. The molar ratio of oxalate/calcium varies greatly from 2–7 (spinach, rhubarb), about 1 (potato *Solanum*) to less than 1 (lettuce, cabbage, peas).

Crystals of calcium oxalate may occur in apparently normal cells of the plant or they may be located in idioblasts. These are membrane-enclosed chambers which determine the shape of the crystals. The crystal form varies from plant to plant and includes needle-like raphides (Fig. 5.2 and 5.3) and mace-like druses (Fig. 5.4b) which are aggregates of crystalline plates (Sunell and Healey 1979). Many raphides are H-shaped in cross-section with grooves along most of their length (Fig. 5.3a) and they also contain barbs (Fig. 5.3b, 5.4a). They are produced from membrane-limited raphidosomes and it is postulated that a membrane calcium pump concentrates Ca^{2+} that combines with oxalate, which is assumed to diffuse freely through these and other membranes (Ledbetter and Porter 1970). Crystal form and distribution are under genetic control and play a specific role in the physiology of the plant (Smith 1982).

There are several different pathways for the synthesis of oxalates in plants; the one most investigated is the conversion of glycollate to glyoxylate and glyoxylate to oxalate. The glycollate may be obtained from two or three different chemicals within the plant (Smith 1982). The function of oxalates and calcium oxalate in plants has not been clarified. Five possible functions are as follows:

(1) It is an end product or excretory product in metabolism and tends to accumulate in the plant with increasing age. Its concentration is higher in the leaves which are lost at abscission and its toxicity is removed by deposition as calcium oxalate crystals. (However, although oxalic acid is toxic to animals, it is not known to be toxic in plants, some of which accumulate it at high concentration, and in some cases it may actually be metabolised (Smith 1982)).

(2) Crystals of calcium oxalate may represent stores for excess calcium that is superfluous to metabolic requirements.

(3) Deposits of calcium oxalate may represent storage reserves (Sunell and Healey 1979; Smith 1982). There is evidence of use of calcium oxalate during germination of seeds and from stems during bud break (Smith 1982), and that it is accumulated and resorbed during growth of taro corms (Sunell and Healey 1979).

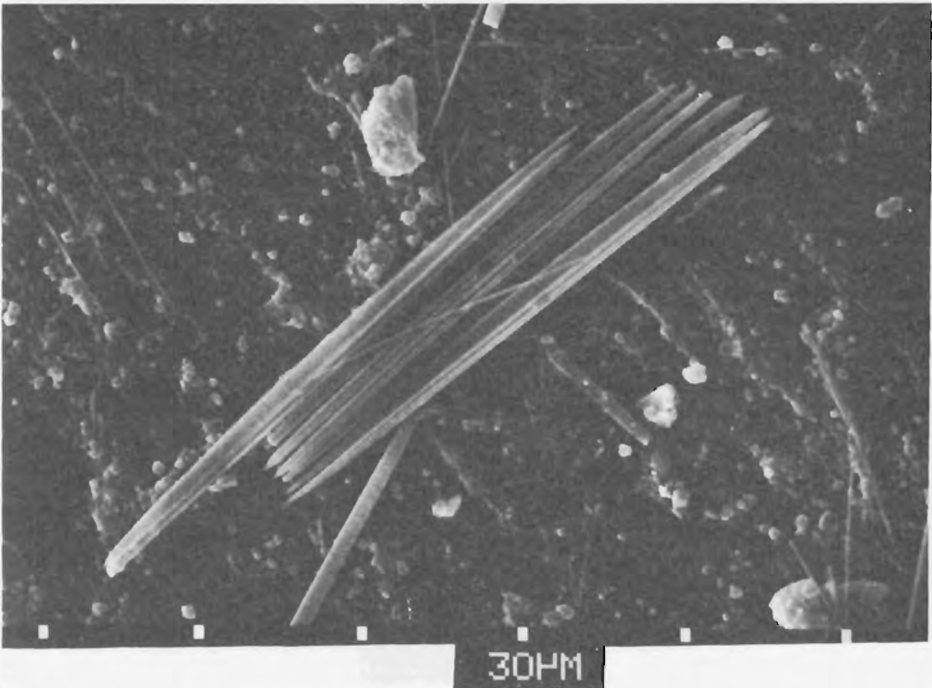
(4) Sharp calcium oxalate crystals (raphides) may act as a toxic or mechanical defence against grazing invertebrates or mammals.

(5) Because of the almost universal occurrence of calcium oxalate in plants it must have a role in metabolism. It has been proposed that it regulates intracellular pH balance (Raven and Smith 1976).

It is not proposed to discuss these possibilities further, but to note that explanations (1) and (3) appear to be mutually exclusive.

5.3.1 Medical Effects of Intake of Oxalate and Calcium Oxalate

There have been several documented cases in which the consumption of rhubarb leaves (cooked and uncooked) have proved fatal, and this has been ascribed to their



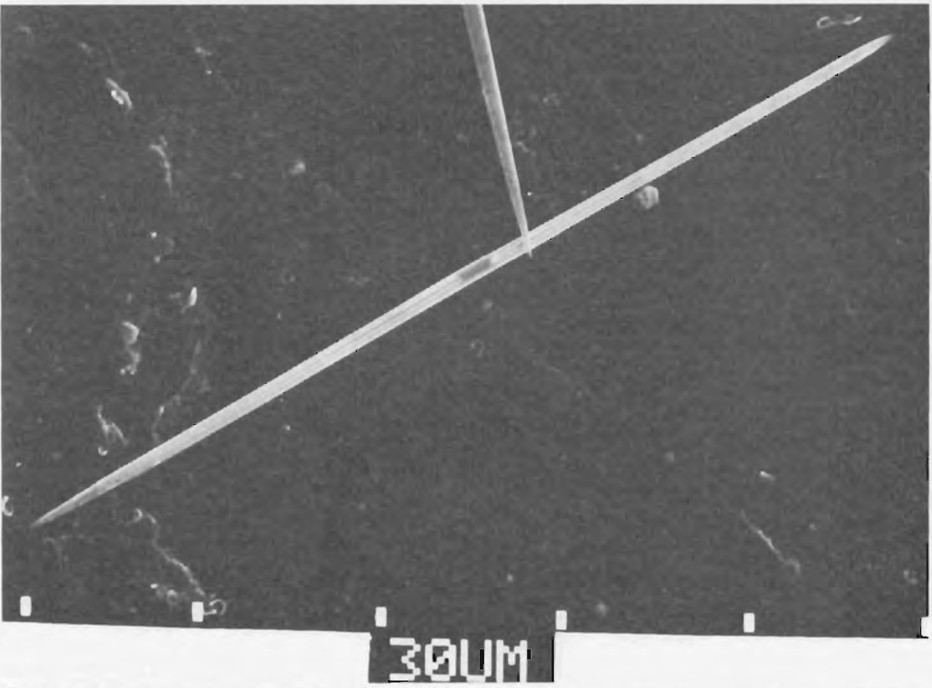
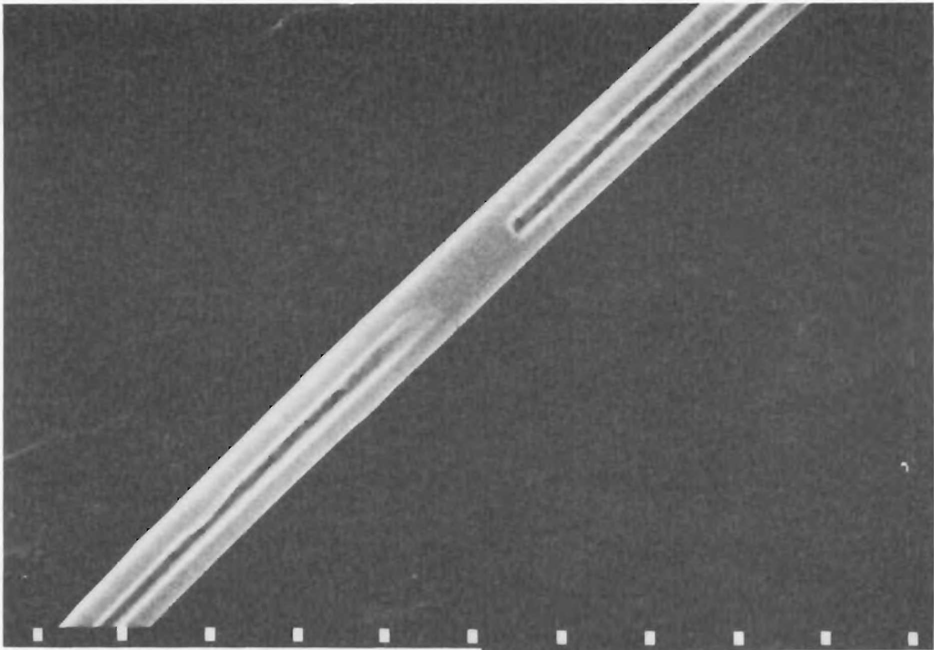


Fig. 5.2 **(a)** (*top*) Scanning electron micrograph of aligned calcium oxalate raphides from giant taro (cv Viagaga, Fiji), length about 100 μm, showing raphides that have a long tapering point at one end and an abrupt point at the other end. **(b)** (*bottom*) Single raphide, length 170 μm, of giant taro from Solomon Islands showing long tapering end, short abrupt end and a line down centre of the raphide.



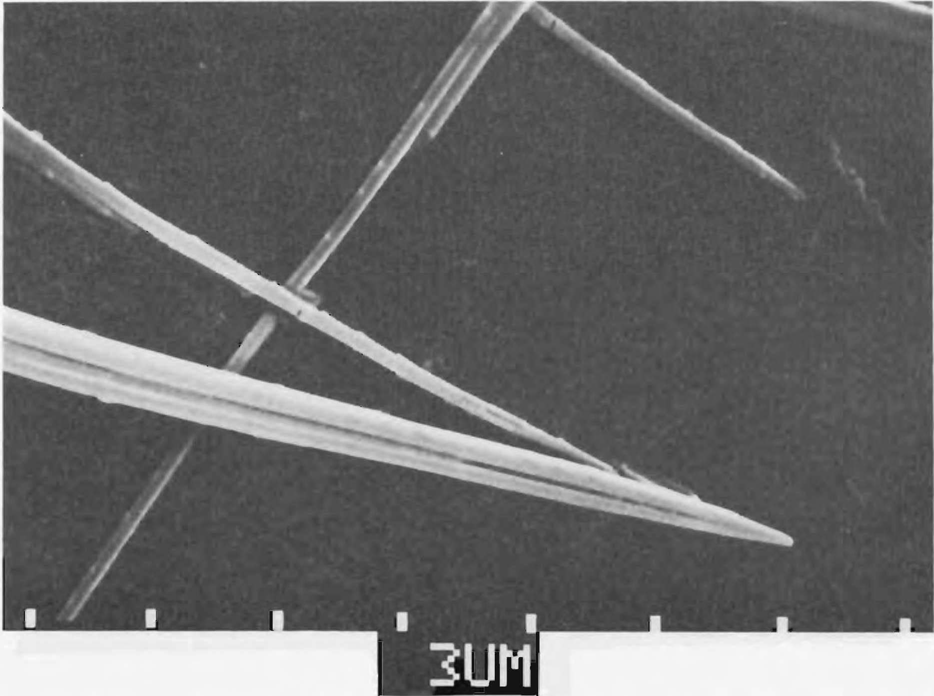
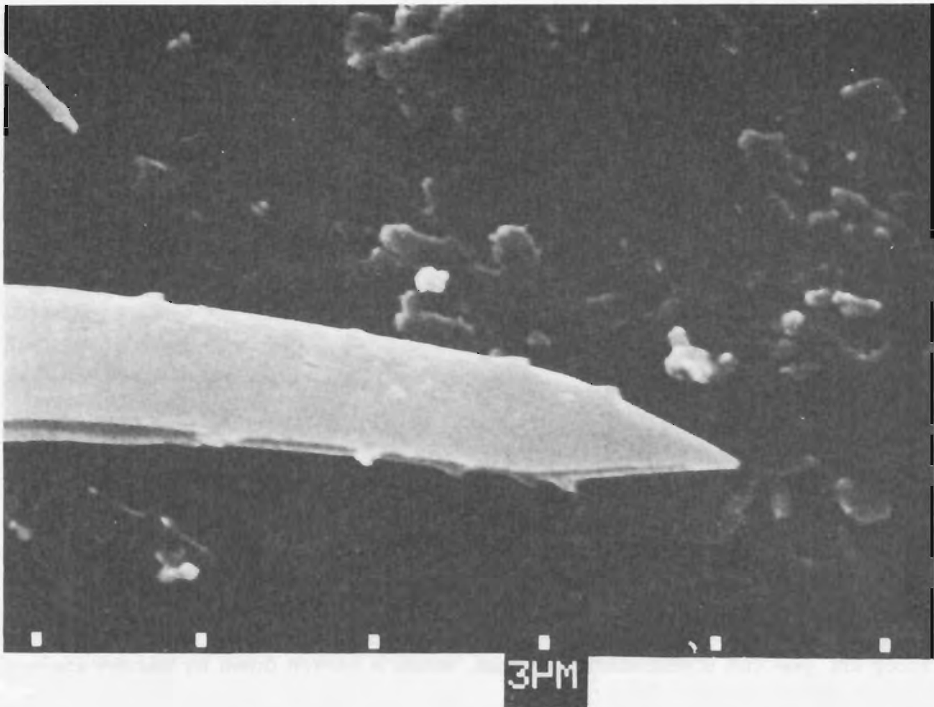


Fig. 5.3 (a) (*top*) Part of a raphide (Fig. 5.2a) at higher magnification showing a groove which is interrupted near the centre of the raphide (Nixon 1987). **(b)** (*bottom*) Thick and thin raphides from taro *Colocasia* cv Tiko from Solomon Islands. In the thin raphide (a) the barbs are oriented in such a way that they would promote the entry of this end of the raphide into the tissue (Nixon 1987).



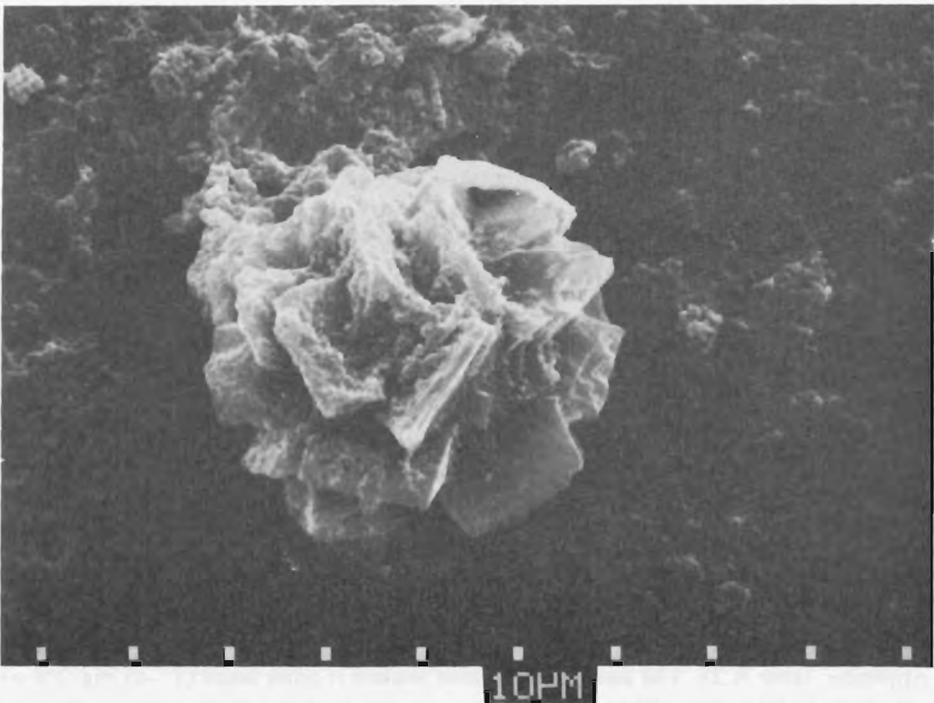


Fig. 5.4 **(a)** (*top*) The abrupt end of a raphide from Fig. 5.2a, showing barbs which are oriented in such a way as to impede the entry of this end of the raphide into the tissue (Nixon 1987). **(b)** (*bottom*) Scanning electron micrograph of a druse of calcium oxalate from giant taro, cv Viagaga, Fiji (Nixon 1987).

content of oxalic acid. The ingestion of a large dose of oxalic acid causes corrosive gastroenteritis, shock, convulsive symptoms, low plasma calcium, high plasma oxalates and renal damage. However, the comparison of symptoms of rhubarb toxicity with those caused by ingestion of a fatal dose of oxalic acid (5 g or more), leaves doubts as to whether the toxicity of rhubarb leaves was not due to some other source such as toxic anthroquinone glycosides (Fassett 1973).

Chronic effects of ingestion of foods containing oxalates include: (1) deposition of calcium oxalate crystals in the kidneys (Connor 1977) and the occurrence of stones in the urinary tract (Passmore and Eastwood 1986); and (2) reduction in bioavailability of calcium (Hodgkinson 1977; Kelsay 1985). With regard to the first problem, humans excrete small crystals of calcium oxalate in the urine. Most of the urinary oxalate is thought to be derived from ascorbic acid and glycine and only a relatively small fraction derives from dietary oxalate (Fassett 1973; Passmore and Eastwood 1986). Increases in urinary oxalate, calcium, uric acid and cystine increase the risk of stones, hence the ingestion of large amounts of oxalate or calcium may exacerbate stone formation (Passmore and Eastwood 1986). In respect of the second problem, the bioavailability of calcium has been reduced in experiments on rats and humans fed a moderately high fibre diet, in which additional oxalic acid was given as spinach and in other ways (Hodgkinson 1977; Kelsay 1985).

The ingestion of insoluble calcium oxalate is a different situation again, and studies have shown that calcium oxalate is only poorly utilised by humans when compared with more soluble oxalates (Hodgkinson 1977). On the other hand cows, sheep and pigs can utilise calcium oxalate, which is broken down by microorganisms (Brune and Bredehorn 1961).

5.3.2 Calcium Oxalate, Soluble Oxalate and Free Calcium Content of Root Crops

Using the methods described in section 2.23 (Holloway et al. 1988) it was possible to determine the total amount of oxalate which equalled insoluble calcium oxalate plus water-soluble oxalate. By determination of water-soluble oxalate the amount of calcium oxalate was obtained by difference. The free calcium, i.e. calcium not combined as insoluble calcium oxalate, was obtained from the difference between the total amount of calcium (sections 2.15 and 2.16) and the calcium combined as calcium oxalate.

Data on the gradients of concentration of oxalate and calcium oxalate in corms of giant taro and taro *Xanthosoma* are given in Table 5.1. There was a large decrease in concentration of total oxalate and calcium oxalate from the skin into the centre of the large corm of giant taro, and a much smaller gradient of total oxalate for taro *Xanthosoma*. It was found by light microscopy that a similar radial gradient of concentration of calcium oxalate raphides occurred in taro *Colocasia* (Sunell and Healey 1979). A high concentration of needle-shaped calcium oxalate raphides (see Fig. 5.2) located near the skin of the corm would appear to offer a useful defence against attack by grazing animals. This tends to support the fourth suggestion in section 5.3 with regard to the function of oxalate.

The content of total oxalate, soluble oxalate, calcium oxalate and free calcium for the various tubers and corms is given in Table 3.15 and for taro *Colocasia* leaves in Appendix Table A.23. The amount of soluble oxalate is quite small (17–45 mg/100 g) for all root crops and, although larger for taro leaves (127 mg/100 g), is still of the same magnitude as that which occurs widely in vegetables and fruits (Fassett 1973). The mean value for water-soluble oxalate of taro *Colocasia* corms of 32 mg/100 g obtained by Wills et al. (1983) agrees well with our value of 35.

Table 5.1. Gradients of oxalate content for corms of giant taro and taro *Xanthosoma*.[a]

Sampling position across a radial section	Giant Taro, cv Fui			Taro Xanthosoma total oxalate[b]	
	Total oxalate	Soluble oxalate	Calcium oxalate	cv 1	cv 2
skin	310	ND[c]	451	–	–
1 cm below skin	135	10	182	139	86
2 cm below skin	–	–	–	112	74
centre of corm	58	ND[c]	84	106	64

[a] Mg/100 g fresh weight.
[b] From PNG (Table A.26). A decrease of concentration of oxalate was also noted from the proximal to the distal end of the stem.
[c] ND = not detected.

The calcium oxalate content of giant swamp taro, elephant foot yam, taro leaves and the skin of giant taro are all about 400 mg/100 g, which is 10–20 times that found for the other root crops. It is interesting to speculate that, in view of the gradient of concentration of raphides already established for several aroids (see above), the concentration of calcium oxalate in the skin of giant swamp taro and elephant foot yam may be much greater than the average value of 400 mg/100 g. As already mentioned, such high levels of calcium oxalate would appear to act as a useful defence mechanism against attack by grazing animals.

The amount of free calcium, i.e. calcium not combined as calcium oxalate, shown in Table 3.15 appears adequate for human nutrition for all root crops except taro *Xanthosoma*, where it is zero, and for yams, where it is small. The excellent bones and teeth of the Pacific Islanders attest to adequate levels of calcium intake. The low incidence of kidney stones amongst atoll dwellers (Parkinson, S., pers. comm.), where giant swamp taro and taro leaves are commonly eaten, is consistent with the result that calcium oxalate is not digested to an appreciable degree (section 5.3.1).

5.4 Acridity of Edible Aroids

The family Araceae includes the five genera of the edible aroids: *Colocasia, Xanthosoma, Alocasia, Cyrtosperma* and *Amorphophallus*. The edible aroids and eight other genera of the Araceae have been reported to be acrid, i.e. to cause a sharp irritation and burning of the throat and mouth on ingestion of uncooked material (Sakai 1979). For example, if *Dieffenbachia* (dumb cane) is chewed, salivation and swelling of the tongue occurs which may interfere with swallowing and breathing for periods up to 1 week. The acrid compound(s) may cause temporary sterility and has been directly linked to death of children and of many experimental and domestic animals (Fochtman et al. 1969; Ladeira et al. 1975; Sakai 1979; Tang and Sakai 1983).

Different degrees of acridity are found in the edible aroids, with some cultivars of taro *Colocasia* and *Xanthosoma* showing only slight or no acridity. The acridity is greater if the root crop experiences adverse growing conditions such as drought or poor soil. *Cyrtosperma* is more acrid, particularly its thick skin, and *Alocasia* and *Amorphophallus* are even more acrid. The latter require removal of a thick layer of skin and a long period of cooking to remove the acridity (Sakai 1979, 1983). Acceptable bread may be produced from a mixture of wheat and taro flour, but may have an astringent flavour due to residual irritant, not fully removed by baking (Crabtree and Baldry 1982).

The acridity of taro acted as a deterrent in feeding trials with mice and rats (Moy et al. 1979; Tang and Sakai 1983) and this is consistent with the suggested physiological role of acridity in the plant, which is as defence against attack by organisms (section 5.3). The acridity of taro imposes limitations on the use of fresh taro corms and leaves by animals, since acrid leaves will not be eaten even by sheep and goats. According to Tang and Sakai (1983) about one-half of the total fresh weight of the plant is not utilised, which represents a considerable loss in the use of this crop in the tropics. A traditional method for removal of acridity involves anaerobic fermentation in an underground pit for several weeks (Carpenter and Steinke 1983; Parkinson, S., pers. comm.). Other methods include prolonged baking, boiling or extraction with ethanol (Moy et al. 1979). There is also the possibility of selection/breeding of non-acrid cultivars, which would be expedited by the development of a simple field test for acridity. Whilst it may be possible to obtain a practical solution to the problem without a full understanding of the nature of acridity, it is much more likely that satisfactory solutions will be achieved only after the nature of acridity has been clarified. This question will now be discussed.

5.4.1 The Nature of Acridity

Acridity of edible aroids was reported by Sir Joseph Banks in his journal in 1760 (Banks 1980). It has been studied over the years since that time (Black 1918; Tang and Sakai 1983) and two major types of explanation have been given about the causes of acridity.

1. Acridity Due Simply to Calcium Oxalate Raphides As already discussed in section 5.3, the calcium oxalate raphides that occur in the edible aroids are needle-like crystals (Fig. 5.2) about 50–200 μm long and about 2–4 μm in diameter, often with one end with a long tapering point and the other with an abrupt point. Differences are observed in their size and shape between the different root crops (Sakai and Hanson 1974; Nixon 1987). The crystals have grooves along their length (Fig. 5.3a) and barbs (Fig. 5.3b, 5.4a), the latter oriented in such a way as to promote the entry of the long tapering end and oppose the entry of the abrupt end of the raphide into the tissue.

The mechanism of raphide release from the idioblast cell of the disrupted plant material involves swelling of polysaccharide material within the idioblast cell (which contains a large array of raphides arranged like a sheath of arrows), with the breaking of the cell walls and ejection of the raphides. Forceful ejection may occur in some species (Black 1918) and was suggested as the principal means of irritation, but this is not now considered to be important, because the raphides of other species which give irritation are not ejected with force (Sakai and Hanson 1974).

It has been proposed that the raphide would tend to penetrate the soft tissue of the mouth, or the soft skin of the forearm, by means of its long tapering point (Fig. 5.2b). Entry of the abruptly pointed end would be impeded by the barbs shown in Fig. 5.4a. Once embedded, the crystal would not be readily dislodged because of the presence and orientation of the barbs, which would tend to cause the crystal to move further into the tissue or skin. The lateral grooves would tend to prevent sealing of the wound around the raphide (Sakai and Hanson 1974).

However, there is evidence that this is not, of itself, a sufficient mechanism to explain acridity. First, some nonacrid plants were found to contain raphides with grooves. Second, cooking or ethanol extraction was found to reduce or eliminate acridity, but had no effect on the raphides, barbs and grooves (Tang and Sakai 1983; Nixon 1987). Third, the calcium oxalate content of edible (nonacrid) and nonedible (acrid) taro leaves was the same (Appendix Table A.23). This may be explained in two ways: (1) the nonacrid leaves contain many finer raphides and many more druses (Fig. 5.4b) than the acrid leaves; or (2) the acridity effect is not simply due to raphides.

We have carried out an experiment to test further this point. Raphides were separared from giant taro and a suspension in petroleum ether was found to be acrid by a simple bioassay, using the soft skin of the forearm (Saha and Hussain 1983). The raphides were immersed in methanol at ambient temperature for several days, the methanol was decanted off and the suspension containing raphides was found to be nonacrid. The methanol solution that contained no raphides also gave a negative test for acridity. The material present in the methanol solution was then deposited back onto the nonacrid raphides, by evaporation of the methanol at room temperature in the presence of the nonacrid raphides. The raphides were found to have regained their acridity (Nixon 1987). The only possible explanation of this result would appear to be that there is a chemical compound present on the surface of active raphides which, together with the raphides, gives the acrid reaction. This chemical is soluble in methanol and can be redeposited on the surface of methanol-inactivated raphides, after which they regain their acrid nature (Nixon 1987). We will now consider the nature of the chemical irritant.

2. Acridity Due to Calcium Oxalate Raphides Plus Chemical Irritant There have been a large number of suggestions with regard to the nature of the acrid material including a proteinase, alkaloid, glucoside, hormone or sapotoxin (Walter and Khanna 1972).

A proteinase has been observed in the juice expressed from *Dieffenbachia* (Fochtman et al. 1969; Walter and Khanna 1972) and its activity in a biossay on the tongues of rats was shown to be decreased by trypsin digestion of the juice. The toxicity of the juice was attributed to a proteinase (Fochtman et al. 1969). Using a similar type of bioassay on the mouths of guinea pigs, however, other workers found that the active material did not contain nitrogen and hence could not have been a protein (Ladeira et al. 1975). A proteinase was extracted from taro corms in an amount that was related to the acridity of the cultivars, but the extract was not tested for acridity (de la Pena and Pardales 1984). Our experiments on the methanol extract containing the chemical irritant (see above) have given a negative test for protein (Nixon 1987). In view of the conflicting results of others and our negative results, we conclude that the chemical irritant is almost certainly not a protein.

Evidence in favour of a glucoside was put forward by Suzuki et al. (1975) who isolated a compound from taro *C. esculenta* var. *antiquorum*, which was claimed to be the diglucoside of 3, 4-dihdroxybenzaldehyde.

Subsequently, Suzuki (1980) separated the same compound from Konnjaku powder, which is produced from the aroid *Amorphophallus rivieri* (Sakai 1983). A further study of *C. esculenta* var. *antiquorum* reported by Tang and Sakai (1983), using the methods of Suzuki et al. (1975), led to the separation not of 3, 4-dihydroxybenzaldehyde but of a related compound 5-hydroxymethylfurfural. However, Saha and Hussain (1983) found the diglucoside of 3, 4-dihydroxybenzaldehyde in corms of taro *Colocasia* and in giant taro. In all this work there was little evidence that the compounds separated were in fact chemical irritants and the chemical evidence in support of the identities of the compounds proposed was not convincing. This, together with the conflicting result of Tang and Sakai (1983) and various reports that the acrid material was unstable in solution, leads to the conclusion that these compounds are probably not the chemical irritant.

Of the other compounds proposed in the list (see above), alkaloids are probably not present (Sakai and Hanson 1974). We are currently working on the elucidation of the nature of the chemical irritant.

Table 5.2. Summary of data related to the possible protective role of chemicals present in aroids.

Aroid and plant part	Diseases of plant in the South Pacific[a]	Chemicals present, mean concentration and gradient within the corm		
		Trypsin inhibitor (% of crude protein)	Calcium oxalate[b] (mg/100 g)	Acridity
Taro *Colocasia*, corm	large numbers of pests and diseases	2.3, no gradient	43, gradient skin high, centre low[c]	edible cv are low, some high
Taro *Colocasia*, leaf	large number of pests and diseases	0	400	edible cv are low, non-edible cv are high
Taro *Xanthosoma* corm	less subject to pests and diseases than *Colocasia*	<0.1	23, gradient skin higher, centre lower[e]	as for *Colocasia* corms
Giant taro *A. macrorrhiza*	hardy plant, resistant to pests and diseases	19–60[d], linear gradient skin low, centre high	37, gradient skin high, centre low[e]	high acridity often concentrated in and near skin
Giant swamp taro *C. chamissonis*	resistant to insects and diseases	0.8, no gradient	399	some acridity may be present in skin and surface layers
Elephant foot yam *A. campanulatus*	resistant to pests and diseases	very low[f]	382	edible cv are usually low, but wild forms high[g]

[a] See Chapter 1.
[b] includes raphides and druses. Data from Tables 3.15, A.23 and 5.1.
[c] Sunell and Healey (1979).
[d] This trypsin inhibitor also strongly inhibits chymotrypsin.
[e] See Table 5.1
[f] Sumathi and Pattabiraman (1975).
[g] Sakai (1983), Sastrapradja et al. (1984).

5.5 Possible Physiological Role of Proteinase Inhibitors, Calcium Oxalate and Acridity

The possibility that the edible aroids produce chemicals (allelochemicals) to provide a defence against attack by microorganisms has been proposed for proteinase inhibitors (section 5.2.1), calcium oxalate (section 5.3 and 5.3.2) and the acrid factor (section 5.4). In Table 5.2 a comparison is made between the pest and disease resistance of the plant in the South Pacific, with the levels of these allelochemicals present in the plant.

Giant taro corms (stems) are unique amongst the aroids studied in being above ground. As a result of this exposure they would be expected to have a higher apparency, i.e. they are more susceptible to discovery by their enemies (Feeny 1976), than if the corm was located underground. The fact that the corm is resistant to pests (including white ants) and diseases may be explained by its very high content of trypsin/chymotrypsin inhibitor, which is concentrated in the interior of the corm, whence it may perhaps be mobilised for action at any site of attack by organisms (Hammer 1987; Bradbury and Hammer 1988). It also has a high level of acridity, often concentrated near the skin and calcium oxalate concentrated just below the skin. Giant swamp taro is also resistant to pests and diseases, but is located underground in swampy conditions and hence is likely to be less apparent to pests and diseases than giant taro. Thus, a lower level of allelochemicals might be expected in giant swamp taro, which in fact is the case, since the concentration is very much less of a trypsin inhibitor that does not inhibit chymotrypsin. Also, we have found the corms to be much less acrid than giant taro, although their concentration of calcium oxalate is much higher (Table 5.2). Elephant foot yam is similar in Table 5.2 to giant swamp taro and hence needs no further comment.

Taro *Colocasia* corms and leaves are subject to a large number of pests and diseases. The corms are located underground like giant swamp taro and are therefore appropriately compared with it. The commonly used cultivars of taro are less acrid than giant swamp taro, they contain only one-tenth the amount of calcium oxalate, but they do have a larger amount of trypsin inhibitor. The generally lower levels of defensive chemicals of taro, as compared with giant swamp taro, may account for the greater susceptibility of taro to disease. The leaf of taro *Colocasia* has a higher apparency than the underground corm and thus it is not surprising that the leaf is usually more acrid; in some cases the leaf is acrid and the corm of the same cultivar is non-acrid (see Appendix Table A.23). The calcium oxalate content of the leaf is ten times that of the corm, but the former has no trypsin inhibitor.

Taro *Xanthosoma* corms are less subject to pests and diseases than taro *Colocasia* corms, but the reason for this is not obvious from Table 5.2. They both have about the same levels of calcium oxalate and acridity, and *Xanthosoma* has much less trypsin inhibitor than *Colocasia*. Perhaps the low level of pests and diseases of *Xanthosoma* is more related to its relatively recent introduction into the region, with the possible absence of pests and diseases which are prevalent in other places. On the other hand, *Colocasia* has been indigenous in the region for many hundreds of years and hence pests and diseases abound.

Chapter 6. Effects of Environmental Constraints on Yield and Composition

There are a large number of environmental factors that affect the yield and composition of tubers or corms of root crops, but the most important ones are shown in Fig. 6.1 (Hahn 1977). The yield of dry matter of the tuber root depends on the photosynthetic activity of the leaves (the source), the ability of the plant to translocate assimilates from the leaves to the tubers (the sink), and the capacity of the tubers to capture the assimilates. The plant physiology of this system for sweet potato is discussed by Hahn (1977) and Hahn and Hozyo (1980). It is not intended to repeat this in detail here, but to note the observed effects of soil moisture, solar radiation and nutrients (N, P, K), and the length of growing season on sweet potato yield and the composition of the tuber. Sweet potato is chosen as an example rather than any other root crop because: (1) there appears to have been more studies with sweet potato; and (2) most of our environmental work has been with sweet potato. The effect of any environmental constraint such as soil moisture on yield and composition may be different for other root crops.

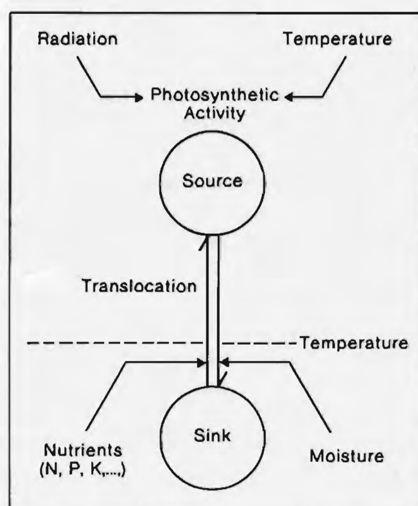


Fig. 6.1 The sweet potato plant is shown diagrammatically as a source, which represents the photosynthetic activity of the leaves and translocation of assimilates to a sink, which represents the tubers. The most important environmental factors that affect dry matter production are shown (after Hahn 1977).

6.1 Environmental Constraints on Yield and Composition of Sweet Potato: Literature Review

6.1.1 Soil Moisture Content

High moisture content (>600 mm rainfall + irrigation over 5 months) has been shown to decrease yield by decreasing both tuber weight and tuber numbers per plant on alluvial clay loam soil (King 1985), as a result of decreased aeration of the tuberous roots which in turn limits tuberous root initiation and development (Hahn and Hozyo 1980; Wilson 1982). A significant negative correlation has been found between rainfall and tuber production and a significant positive correlation between vine production and rainfall (Gollifer 1980). Hide et al. (1984) also found a negative correlation between rainfall and tuber yield. In essence, high soil moisture content gives good shoot growth but poor tuberisation, primarily because of poor soil aeration. On the other hand, although sweet potato is a drought-resistant crop, yield is decreased by lack of soil moisture (Tsuno undated). Yields have therefore been increased by irrigation, which increased soil moisture levels up to 25–50% of the water-holding capacity of the soil (Tsuno undated; Hammett et al. 1982b).

Three studies in the USA have shown that sweet potato tuber quality was reduced by high soil moisture. Constantin et al. (1974) and Hammett et al. (1982b) found that supplemental irrigation caused a decrease in dry matter and crude protein contents and in the colour of the fresh and processed roots. Ton and Hernandez (1978) studied the effect of high soil moisture levels on sweet potato quality. They found increased losses from rotting of tubers at harvest and increased shrinkage losses during storage as well as other smaller effects.

6.1.2 Length of Growing Season (Time to Harvest) and Method of Harvest

In three studies it was found that there was an increased yield of sweet potato tubers with increase of the harvest date (Scott and Bouwkamp 1974; Purcell et al. 1976a; Ashokan et al. 1982). Two other studies in the Lowlands of PNG showed that a maximum tuber yield was reached (Jamieson 1968; Bourke 1985b). The yield maximum was found to occur earlier in more depleted soil and maximum flowering was considered a useful indicator of the point of maximum yield (Jamieson 1968), but other factors such as short day-length also promote flowering (Linton, P., pers. comm.).

Comparisons have been made between single harvesting of all tubers versus progressive harvesting of the largest tubers (Rose 1979; Bourke 1985a). The latter is commonly practiced in the Highlands of Papua New Guinea whereby mature tubers are hand-dug leaving smaller tubers undisturbed. The results of the different studies have been summarised by Bourke (1985a) who concluded that the two techniques gave similar bulking rates in terms of total tuber yield, but that the progressive harvesting gave a lower bulking rate for marketable tubers and a higher bulking rate for small tubers (<100 g) which are normally fed to pigs.

Purcell et al. (1976a) observed a slight but significant decrease in the dry matter content from 27.3 to 25.7% and in the crude protein content from 1.53 to 1.33% over the period from 102 to 165 days after planting. Ashokan et al. (1982) found a decrease in starch content from 90 to 120 days after planting; reducing sugars first increased until 105 days after planting and then decreased. The concentrations of Ca, Mg, Fe, Mn and B in the tubers were fairly constant over time after planting and there were reductions in N, P, and possibly K, but the total amount of minerals accumulated by the tubers increased markedly in all cases. The uptake per plant of N, K, and Mg was

similar to the amount supplied per plant, but for P the uptake was about one-third of that supplied by fertilizer application. The results emphasise the necessity of maintaining adequate levels of readily leached nutrients such as N, K and Mg during crop development (Scott and Bouwkamp 1974).

6.1.3 Fertilizer Application (N, P, K)

It is clear from the foregoing and Fig. 6.1 that an adequate supply of N, P, K and possibly other nutrients is required by the growing plant. The yield of sweet potato tubers is increased by supply of these nutrients as fertilizer in soils of marginal fertility, but if there is already an abundance of nitrogen, potassium and phosphorus present in the soil, increasing soil levels of these nutrients will not lead to an increase in yield (Purcell et al. 1982; Nicholaides et al. 1985). In general, addition of N and K separately or as a combined fertilizer (N, P, K) has increased yields (Kimber 1975; Purcell et al. 1982; Hahn 1977; Mascianica et al. 1985; Bourke 1985b). Nitrogen increases the leaf area index and thence increases mean tuber weight and yield (Bourke 1985b). Potassium uptake early in the crop cycle increases the number of tubers per plant and the mean tuber dry weight and hence increases the yield (Hahn 1977; Bourke 1985b).

In general, an increase in the level of N fertilizer caused an increase in tuber nitrogen content (Kimber 1975; Purcell et al. 1982; Sharfuddin and Voican 1984). Increased levels of potassium lead to reduction in the dry matter content of tubers (Duncan et al. 1958; Fujise and Tsuno 1969; Bourke 1985b), an increase in nitrogen content in one case (Sharfuddin and Voican 1984) and no change in another (Purcell et al. 1982).

6.2 Present Environmental Studies on Yield and Composition of Sweet Potato

6.2.1 Length of Growing Season (Time to Harvest)

The results of a sweet potato trial of five cultivars planted on the islands of Guadalcanal and Malaita in Solomon Islands are given in Table 6.1. The trials were harvested at four different times from 90 to 165 days after planting. The first site (Tenaru, Guadalcanal) had about an optimal rainfall of 504 mm over 5 months and the second site at Fote, Malaita, had 1155 mm over the same period. No irrigation or fertilizer was used.

There was a highly significant increase in tuber yield over the 165 days of the trial at Tenaru in agreement with three studies elsewhere (section 6.1.2) and a vine yield that increased up to 115 days and then became steady. In contrast, the tuber yield at Fote was the same as at Tenaru after 90 days, but thereafter the Fote crop failed to develop further tubers or leaves until the last very wet period, when the top weight increased greatly, probably because of the high rainfall. Wet conditions, particularly late in the life of the crop as occurred at Fote, were shown by King (1985) and others (section 6.1.1) to lead to low tuber yields and a small number of tubers per plant.

The moisture content of the tubers harvested at Tenaru reduced significantly from 90 to 165 days after planting to a value that corresponded with the constant value for the tubers from Fote. This contrasts with our irrigation results (section 6.2.2) and the results of Constantin et al. (1974), Ton and Hernandez (1978) and Hammett et al. (1982b) which showed that high soil moisture levels due to irrigation caused increased moisture in the tubers. Purcell et al. (1976a) observed a significant, small increase of moisture content from 72.7 to 74.3% with increased length of growing season, which is different from the decrease observed at Tenaru or the constant value obtained at

Fote. Clearly, the situation is complex and requires a more detailed study with inclusion of soil moisture measurements.

The protein content of tubers at Tenaru increased significantly from 90 to 140 days and those at Fote increased very significantly over the same period and peaked at 140 days. Purcell et al. (1976a) reported a significant small decrease from 1.53 to 1.33%, from 102 to 165 days after planting. As with moisture content, there are contradictions between the behaviour observed in the three cases. The significantly higher protein content of Fote tubers at each time of harvest as compared with Tenaru tubers of the same cultivar is probably due to higher soil N at Fote (Table 6.1).

The calcium and iron levels at Tenaru and Fote were essentially constant over different times of harvest; similar results were found by Scott and Bouwkamp (1974). However, the iron content of sweet potato tubers from Fote was significantly greater than that from Tenaru, which may have been due to reduced iron uptake from the Tenaru soil because of its higher pH as compared with the Fote soil (Table 6.1).

6.2.2 Irrigation Trial

The effects of irrigation on the moisture and protein contents of sweet potato tubers from a trial in Papua New Guinea are shown in Table 6.2. There was a significant increase in moisture content and decrease of protein content with the use of 50 mm irrigation/month in the first and the second harvests, and a further increase in moisture content (significant in one case) with increase in irrigation from 50 to 200 mm/month. This was in agreement with earlier work of Constantin et al. (1974)

Table 6.1. Sweet potato from Solomon Islands, five cultivars, four harvest times, and two sites[a].

Days after planting and date:	*90* *July 3*	*115* *July 27*	*140* *Aug. 21*	*165* *Sept. 15*
First Site, Tenaru, Guadalcanal[b]				
Total tuber yield (t/ha)	6.4(1.9)	10.3(1.5)	15.0(2.0)	20.2(3.7)
Vine yield (t/ha)	15.3(1.2)	19.0(2.8)	17.5(1.1)	18.9(2.6)
Moisture %	76.1(3.9)	75.3(4.1)	71.7(4.8)	70.8(4.0)
Protein %	0.64(0.20)	0.71(0.05)	0.94(0.10)	0.94(0.27)
Calcium (mg/100 g)[c]	23	18	17	25(9)
Iron (mg/100 g)[c]	0.29	0.29	0.30	0.31(0.03)
Second Site, Fote, Malaita[d]				
Total tuber yield (t/ha)	5.6(3.1)	7.2(2.6)	6.6(2.0)	5.3(2.0)
Vine yield (t/ha)	9.8(2.6)	9.0(1.0)	7.2(3.5)	17.6(4.9)
Moisture %	70.6(3.1)	70.6(1.7)	69.5(2.0)	70.8(2.4)
Protein %	0.93(0.25)	1.18(0.22)	1.73(0.25)	1.44(0.28)
Calcium (mg/100 g)	24	15	22	37(7)
Iron (mg/100g)	0.43	0.30	0.44	0.49(0.02)

[a] This was a nonreplicated trial at the two sites. Cultivars numbered 80, 108, 213, 268, and 275 were planted at each site on 3 April 1985. Ten tubers of each cultivar were bulked together for analyses at 90, 115 and 140 days after harvest but at 165 days after harvest, each of the 10 tubers was analysed separately. Results given in the table are the mean and standard deviations (given in parentheses) from the five cultivars. Trends within each of the cultivars were essentially the same as that obtained from the mean values.

[b] Rainfall at Tenaru for A, M, J, J, A was 99, 99, 52, 120 and 134 mm, total over 5 months 504 mm. Soil was deep, freely to imperfectly drained montmorillonitic clay derived from calcareous alluvium, pH 6.4, N = 0.15%, K = 0.85 meq/100 g.

[c] These calcium and iron results were obtained on only one cultivar, number 80.

[d] Rainfall at Fote for A, M, J, J, A was 166, 225, 190, 168 and 406 mm, total over 5 months 1155 mm. Soil was deep, freely drained, strongly weathered clay derived from coralline limestone, pH 5.2, N = 0.27%, K = 0.34 meq/100 g.

Table 6.2. Sweet potato from Lowlands of Papua New Guinea, three levels of irrigation and two times of harvest.[a]

Amount of irrigation (mm/month)	*First harvest (Oct 1985)*		*Second harvest (Nov 1985)*	
	% Moisture	*% Protein*	*% Moisture*	*% Protein*
nil	68.9(2.1)	1.37(0.31)	70.9(2.4)	1.32(0.23)
50	73.4(1.3)	0.62(0.07)	74.9(4.7)	0.76(0.25)
200	77.4(2.0)	0.68(0.59)	75.6(1.3)	0.89(0.09)

[a] The cultivar L11 grown on a clay loam site at Laloki Research Station, near Port Moresby, with irrigation as indicated after establishment of the crop. Results are the mean of six analyses from six tubers at each level; standard deviations in parentheses.

and Hammet et al. (1982b) who found a decrease in dry matter and protein content with supplemental irrigation (section 6.1.1).

6.2.3 Fertilizer and Gypsum Trial

The effects of the addition of N and K on the moisture and protein content of sweet potato grown under very wet conditions in the Highlands of Papua New Guinea are shown in Table 6.3. The moisture content was generally reduced on addition of increasing amounts of nitrogen fertilizer but was not affected by added potassium, contrary to results of other workers (section 6.1.3). In the absence of added potassium, there was a linear increase in tuber protein content with increasing amounts of added nitrogen, a result similar to that of other workers (section 6.1.3). However, the effect on protein content of added nitrogen was different when combined with potassium. In this case there was a very large increase after the first addition of nitrogen followed by decreases after subsequent additions. The reason for this behaviour is not clear. Comparison between the percent protein of tubers grown at the two levels of K and different N levels showed variable responses. Similar variability of results was obtained by Purcell et al. (1982) and Sharfuddin and Voican (1984) (section 6.1.3). The very high rainfall of the site and its sandy nature indicates that soil nutrients were readily leached out and this would be consistent with the large responses observed to use of fertilizer.

Table 6.3. Influence of N and K fertilizer on moisture and protein contents of sweet potato from Papua New Guinea[a]

Potassium added kg/ha	*Nitrogen added kg/ha*	*% Moisture*	*% Protein*
0	0	72.3(1.5)	0.84(0.12)
0	100	73.4(0.9)	1.08(0.12)
0	200	71.5(2.5)	1.32(0.28)
0	400	70.3(0.8)	1.96(0.27)
150	0	74.4(0.5)	0.87(0.18)
150	100	70.8(2.0)	1.67(0.28)
150	200	72.1(2.5)	1.37(0.24)
150	400	68.3(1.4)	1.19(0.07)

[a] Cultivar L31 was grown at Kiunga (Alice Trial 1, block 2), in sandy soil, rainfall 5000-7000 mm/year, harvested October 1985. Results are the mean of five analyses on five tubers at each level; stardard deviations in parentheses.

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Appendix Tables

The appendix contains detailed nutrient analyses for the various root crops from eight countries of the South Pacific on a cultivar-by-cultivar basis. The cultivars include popular ones grown in research stations, gardens or purchased in the market and also elite cultivars developed in research stations. Relevant data on conditions during growth are given in the individual Tables.

The data base available in the tables has been averaged and summarised to give the overall picture for each root crop in Chapter 3.

All the results recorded in the appendix and throughout the book are given on the basis of the fresh weight of the sample. Numbers given in parentheses in the tables refer to the standard deviation which is obtained from analyses of multiple (usually 3–10) tubers or corms of the same cultivar.

Table A.1. Sweet potato from Solomon Islands.[a]

Sample designation	Yield (t/ha) marketable tubers	Moisture %	Energy[b] (kJ/100 g) E_a	E_b	Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Trypsin inhibitor (TIU/g)	Chymo-trypsin inhibitor (CIU/g)
		a			*b*	*e*	*f*	*g*	*c*	*d*				
Santa Cruz	18.8	74.0	362	414	0.81	17.7	2.42	1.66	0.19	0.63	30.8	0.90	12.2	—
Three Months	19.1	71.9	406	457	0.91	21.0	1.73	1.33	0.16	0.79	31.8	0.41	20.3	—
Western	6.8	68.3	455	513	1.63	22.3	2.70	1.49	0.15	0.87	39.5	0.49	55.7	—
Toni	14.6	73.0	360	430	0.69	19.3	1.13	1.13	0.11	0.76	21.3	0.79	0.0	—
TIS 2498	10.0	70.2	403	479	1.03	20.6	2.05	0.63	0.08	0.75	17.7	0.42	24.3	—
Nawaro	22.8	69.7	418	487	0.87	25.4	2.83	1.85	0.30	0.62	34.7	0.57	49.0	—
Western Province	18.8	66.1	451	550	1.92	19.9	4.55	1.31	0.21	0.88	40.8	0.66	—	—
Teomo	11.6	74.3	328	407	0.52	14.9	3.71	2.06	0.18	0.71	24.6	0.48	—	—
Vaka	12.7	71.1	429	463	0.75	18.3	5.64	2.84	0.43	0.92	31.6	0.48	—	—
158a	9.4	67.4	523	527	1.81	23.8	5.03	2.26	0.21	0.73	39.1	0.69	—	—
40	9.5	76.3	326	373	0.81	14.1	4.23	1.42	0.12	0.54	28.4	0.30	—	—
42	43.0	69.5	409	491	1.63	18.5	3.77	4.62	0.14	0.55	—	0.40	—	—
108	24.0	77.5	307	352	2.50	12.4	3.05	2.08	0.10	0.55	57.0	0.37	25.0	1.27
107	9.1	72.5	356	439	2.13	14.6	4.11	4.71	0.16	0.94	68.4	0.42	24.0	0.96
139	15.1	63.3	517	599	1.75	24.0	4.56	3.89	0.14	0.72	41.2	0.24	—	—
Lai	10.7	72.7	376	435	1.81	16.3	3.85	1.84	0.17	0.91	29.9	0.30	—	—
131	40.0	75.3	319	390	1.88	12.4	4.17	3.93	0.22	0.80	—	0.29	27.0	0.74
37	11.1	72.9	338	432	1.81	12.5	5.59	3.92	0.14	0.87	—	0.46	—	—
45	13.2	89.0	125	152	0.63	5.3	1.30	1.54	0.08	0.31	—	0.16	—	—
50	10.1	69.5	450	491	1.44	20.4	4.30	1.40	0.27	0.62	—	0.49	—	—
Mean[c]		72.2	383	448	1.28	17.7	3.21	2.62	0.17	0.73	35.6	0.47	25.4	0.99
SD		5.1	87	87	0.58	4.9	1.36	1.5	0.09	0.18	13.1	0.18	17.0	0.27

[a] The first six cultivars are mean analyses from two samples each of 3–5 tubers bulked together; the remaining results are from a single bulked sample of 3–5 tubers. Selections grown in a field at Tenaru cropped previously with sweet potato planted mid April, harvested end of October 1983; rainfall usually low in June–August. Western is a popular local cultivar and TIS 2498 a promising introduction from the International Institute of Tropical Agriculture (IITA), Nigeria. For organic acid and calcium oxalate results see Table A.11.

[b] E_a = 17b + 38c + 17e + 16f, E_b = −17.38 (% moisture) + 1699, see sections 2.12 and 2.13.

[c] Sum of a + b + c + d + e + f + g = 97.9.

Table A.2. Sweet potato from Solomon Islands.[a]

Sample designation	*Moisture* %	*Energy (kJ/100 g)*		*Protein* %	*Starch* %	*Sugar* %	*Dietary fibre* %	*Fat* %	*Ash* %	*Calcium (mg/100 g)*	*Iron (mg/100 g)*
		E_a	E_b								
	a			*b*	*e*	*f*	*g*	*c*	*d*		
Vaka	68.1	448	515	2.46	21.6	1.83	0.80	0.25	0.67	34.7	0.46
Ngiriare	69.8	419	486	1.82	20.3	2.52	0.49	0.08	0.65	23.2	0.50
Western Province	66.1	491	550	2.14	24.3	2.20	1.13	0.18	0.64	25.5	0.44
Reefs Jimi	70.4	449	474	2.34	21.8	1.98	1.22	0.09	0.72	12.5	0.40
Sinulu	67.5	483	526	2.93	23.0	2.60	2.33	0.13	0.65	47.8	0.55
Bugotu	68.6	496	507	1.31	24.3	2.67	1.61	0.48	0.72	59.3	0.60
Dingale	71.1	419	463	2.31	20.3	1.78	1.50	0.18	0.91	74.5	0.53
TIS 2498	67.6(1.5)	475	524	2.21(0.42)	21.2	4.53	1.99	0.10	0.61	19.0	0.41
220 MK 10	73.6(0.9)	381	420	2.00(0.26)	16.0	4.43	1.67	0.10	0.67	36.8	0.39
Santa Cruz	71.9(2.7)	402	449	1.76(0.24)	17.3	4.45	1.52	0.17	0.61	50.3	0.40
Three Months	73.6(1.7)	377	420	2.14(0.51)	17.1	2.93	1.50	0.08	0.83	49.6	0.45
Mean[b]	69.9	439	485	2.13	20.6	2.90	1.43	0.17	0.70	39.4	0.47
SD	2.5	46	44	0.42	3.0	1.07	0.51	0.12	0.09	18.8	0.07

[a] Samples arrived November 1984. For the first seven cultivars in the table, five tubers were bulked together for analysis; the last four entries consisted of 10 tubers each, which were analysed separately for moisture and protein using both the Dumas and Kjeldahl methods, which agreed within experimental error. These 10 samples were bulked together for the remaining analyses.

[b] Sum of a + b + c + d + e + f + g = 97.8.

Table A.3. Sweet potato from Tonga.[a]

Sample designation	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Trypsin inhibitor (TIU/g)
		E_a	E_b									
	a			*b*	*e*	*f*	*g*	*c*	*d*			
Melefakahau	77.3	311	356	0.76	15.6	1.74	1.28	0.14	0.99	44.2	0.45	3.6
	(1.2)			(0.18)	(2.2)	(0.47)	(0.24)	(0.03)	(0.07)	(18.2)	(0.24)	
Siale	73.5	356	421	0.46	15.9	4.39	2.16	0.18	0.93	29.9	0.56	—
	(3.3)			(0.08)	(4.9)	(0.69)	(0.67)	(0.04)	(0.14)	(10.7)	(0.12)	
Tongamai	68.4	484	510	0.84	23.8	3.43	1.74	0.29	0.47	31.4	0.35	—
	(2.9)			(0.36)	(3.9)	(0.45)	(0.51)	(0.06)	(0.02)	(3.3)	(0.19)	
Hawaii	68.9	445	501	1.20	22.2	2.52	1.57	0.16	0.65	52.3	0.40	—
	(1.2)			(0.10)	(2.1)	(0.47)	(0.39)	(0.01)	(0.10)	(4.6)	(0.11)	
Halasika	74.2	364	410	1.01	19.2	0.87	1.13	0.18	0.79	20.1	0.47	41.0
	(0.5)			(0.16)	(1.7))	(0.33)	(0.56)	(0.02)	(0.05)	(4.0)	(0.15)	
Mean[b]	72.6	391	440	0.85	19.4	2.59	1.58	0.19	0.76	35.6	0.45	22.3
SD	4.0	75	68	0.31	4.5	1.34	0.59	0.06	0.21	14.7	0.17	26.4

[a] Each result is the mean of analyses on five separate tubers. Three cultivars Tongamai, Hawaii and Melefakahua were planted on 22 September 1983, and harvested 6 April 1984 at Vaini Research Farm, Tongatupu. Siale and Halasika, obtained from nearby farms, were about the same age.

[b] Sum of a + b + c + d + e + f + g = 98.0.

Table A.4. Sweet potato selections from Laloki Research Station, PNG lowlands.[a]

Sample designation	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)
		E_a	E_b								
	a			*b*	*e*	*f*	*g*	*c*	*d*		
L29	70.4	446	475	2.23	21.8	2.19[b]	1.29	0.06	1.06	26.1	0.48
L46	69.7	426	488	1.45	20.7	2.73[b]	1.66	0.14	0.67	24.0	0.64
L18	74.4	361	406	1.80	17.6	1.72[b]	0.62	0.08	0.94	18.7	0.45
L16	75.0	369	396	1.20	17.6	2.89	1.29	0.10	0.76	35.0	0.36
L49	69.9	439	484	2.19	20.5	3.18	0.86	0.07	0.76	16.6	0.61
L9	71.3	440	460	1.28	22.1	2.41	1.39	0.14	0.78	24.0	0.42
L15	69.3	450	495	1.84	22.4	2.17	1.54	0.06	0.86	35.1	0.49
L33	74.5	393	404	1.62	18.5	2.83	1.09	0.13	0.72	33.1	0.51
L43	69.3	456	495	1.72	21.4	3.58	1.08	0.12	0.91	30.2	0.67
Mean[c]	71.5	420	456	1.70	20.3	2.63	1.20	0.10	0.83	27.0	0.51
SD	2.4	36	42	0.36	1.9	0.57	0.33	0.03	0.12	6.8	0.10

[a] Samples arrived November 1984. Six tubers of each cultivar were bulked together and analysed.
[b] Detailed sugar analyses given in Tamate and Bradbury (1985).
[c] Sum of a + b + c + d + e + f + g = 98.3.

Table A.5. Sweet potato from Kuk Research Station, PNG highlands.[a]

Sample designation	*Moisture %*	*Energy (kJ/100 g)*		*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Iron (mg/100 g)*	*Trypsin inhibitor (TIU/g)*
		E_a	E_b									
	a			*b*	*e*	*f*	*g*	*c*	*d*			
Simbul sowar	76.0	380	378	1.17	18.4	2.53	1.32	0.21	0.78	7.5	0.32	1.11
Tomun	73.2	406	427	0.96	21.1	1.65	1.51	0.14	0.72	17.1	0.38	1.70
Po	74.8	361	399	1.12	18.3	1.59	1.31	0.13	0.71	10.7	0.37	0.54
Habare	75.1	324	394	0.90	16.2	1.67	0.85	0.16	0.79	8.6	0.30	0.55
Wanmun	74.6	383	402	1.54	17.3	1.96	1.86	0.16	0.88	26.3	0.40	1.17
Parabea	73.8	373	416	1.29	18.4	2.00	1.70	0.18	0.80	19.0	0.29	7.10
Kariap	71.0	405	465	1.39	19.7	1.89	1.87	0.28	0.79	9.3	0.31	0.77
Sapel	71.0	410	465	1.51	19.8	2.45	1.93	0.22	0.77	14.3	0.70	10.2
Soii	73.1	388	429	1.16	18.8	2.21	1.65	0.33	0.77	12.4	0.35	0.24
Mame	77.0	328	361	1.34	15.3	2.27	1.46	0.25	0.81	12.4	0.32	7.10
Bau	67.9	481	519	1.74	24.7	1.18	1.69	0.34	0.85	10.4	0.34	3.33
Paipa	69.5	425	491	1.38	21.9	1.52	1.40	0.14	0.74	9.7	0.32	1.92
Padua	69.0	465	500	1.43	23.6	1.99	1.40	0.20	0.85	8.2	0.54	10.00
Mean[b]	72.8	393	434	1.30	19.5	1.92	1.53	0.21	0.79	12.8	0.38	3.52
SD	2.9	47	50	0.24	2.8	0.39	0.30	0.07	0.05	5.3	0.12	3.71

[a] Popular cultivars from Upper Mendi and Tari districts of Southern Highlands Province, PNG, arrived December 1984 (Bradbury et al. 1984a, 1985b). Samples were single half tubers used in a weevil experiment.

[b] Sum of a + b + c + d + e + f + g = 98.1.

Table A.6. Sweet potato from Western Samoa.[a]

Sample designation	*Yield (t/ha) marketable tubers*	*Top yield (t/ha)*	*Moisture %*	*Energy (kJ/100 g)*		*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Iron (mg/100 g)*
				E_a	E_b								
03	12.3	19.3	61.2	565	635	2.25	28.4	2.45	1.30	0.14	0.59	25.7	0.60
04	8.0	26.9	69.5	437	491	2.50	20.3	2.42	1.20	0.25	0.61	20.2	0.55
05	9.3	26.9	68.3	449	512	1.56	22.5	1.97	1.27	0.21	0.54	25.3	0.72
08	5.1	25.5	63.7	505	592	1.75	24.3	3.37	1.77	0.22	0.73	56.9	0.94
09	7.7	28.0	67.4	463	528	2.13	22.1	2.70	1.78	0.21	0.55	26.4	0.78
14	7.2	24.9	66.6	440	541	0.63	22.7	2.42	1.24	0.13	0.57	22.1	0.71
Mean			66.1	477	550	1.80	23.4	2.56	1.42	0.19	0.60	29.4	0.72
SD			3.1	51	54	0.67	3.0	0.46	0.28	0.05	0.07	13.7	0.14

[a] Each analysis was made on six tubers bulked together, one tuber from each of six replicates. Planted at Togitogiga 23 February, harvested about 23 June 1985. Popular local cultivars were used.

Table A.7. Sweet potato from Fiji.[a]

Sample designation	*Yield (t/ha)*	*Moisture %*	*Energy (kJ/100 g)*		*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Iron (mg/100 g)*	*Trypsin inhibitor (TIU/g)*
			E_a	E_b									
		a			*b*	*e*	*f*	*g*	*c*	*d*			
Vulatolu	15.4	71.2	342	401	0.71	17.9	1.35	1.72	0.11	0.74	21.3	0.38	—
		(0.90)			(0.10)	(2.2)	(0.08)	(0.15)	(0.01)	(0.10)	(8.3)	(0.03)	
Drividrivi	12.7	76.1	335	376	1.25	17.8	0.46	1.63	0.09	0.74	28.8	0.32	—
		(3.0)			(0.66)	(3.3)	(0.15)	(0.03)	(0.01)	(0.03)	(2.5)	(0.06)	
KRSI	23.1	75.8	324	382	0.61	17.3	0.86	1.75	0.17	0.75	28.2	0.28	—
		(1.6)			(0.04)	(1.8)	(0.27)	(0.14)	(0.02)	(0.09)	(8.5)	(0.09)	
Honiara	34.7	76.2	313	375	0.88	16.7	0.38	1.56	0.22	0.73	15.9	0.38	—
		(1.7)			(0.20)	(1.3)	(0.11)	(0.37)	(0.04)	(0.02)	(5.0)	(0.02)	
TIB 2	29.6	75.1	312	394	0.86	16.4	0.89	1.64	0.10	0.70	16.1	0.38	1.6
		(2.9)			(0.09)	(3.7)	(0.20)	(0.08)	(0.01)	(0.05)	(0.2)	(0.12)	(0.6)
TIB 10	16.3	69.5	451	491	0.81	24.5	1.00	1.66	0.14	0.62	28.1	0.60	—
		(4.4)			(0.16)	(4.4)	(0.23)	(0.30)	(0.03)	(0.06)	(4.1)	(0.11)	
TIS 1499	14.9	72.3	399	442	0.92	21.1	0.91	1.84	0.24	0.80	25.2	0.47	1.2
		(1.3)			(0.23)	(1.9)	(0.18)	(0.32)	(0.04)	(0.06)	(6.0)	(0.05)	(0.5)
TIS 3017[b]	24.2	67.0	472	535	1.16	24.9	1.22	1.75	0.20	0.74	34.9	0.54	5.2
		(1.0)			(0.20)	(1.0)	(0.20)	(0.25)	(0.05)	(0.07)	(8.1)	(0.12)	(6.6)
TIS 3030	26.7	70.1	426	481	1.06	22.7	0.97	1.27	0.18	0.84	21.3	0.50	0.77
		(1.6)			(0.24)	(1.30)	(0.41)	(0.18)	(0.01)	(0.05)	(5.8)	(0.09)	(0.01)
Mean[c]	22.0	72.6	374	437	0.92	19.9	0.89	1.66	0.17	0.74	24.4	0.44	2.2
SD	7.6	3.4	65	59	0.21	3.6	0.31	0.21	0.05	0.06	6.3	0.11	2.0

[a] Three tubers bulked per replication, four replications analysed separately per cultivar. First four cultivars were popular locally, the remainder were imported from IITA, Nigeria. Planted at Koronivia Research Station 28 May, harvested 4 November 1985. Rainfall (mm) and mean temperature (°C) for each month as follows: June 176.3, 23.4; July 213.4, 23.1; August 158.4, 23.1; September 285.9, 23.1; October 345.8, 24.6. Fertilizer levels N:P:K 80:40:160 applied in a band 10 cm from plant, 30 days after planting. Soil, Rewa Series (loam, silty clay loam, clay loam), well drained; FAO:Eutric Fluvisol.

[b] Results for organic acids and calcium oxalate given in Table A.11.

[c] Sum of a + b + c + d + e + f + g = 96.9.

Table A.8. Mineral content (mg/100 g fresh weight) of sweet potato from Solomon Islands and Tonga.[a]

	Minerals											
	Ca	*P*	*Mg*	*Na*	*K*	*S*	*Fe*	*Cu*	*Zn*	*Mn*	*Al*	*B*
Solomon Islands (see Table A.1)												
Santa Cruz	30.8	60.4	19.1	38.9	253	12.3	0.90	0.12	1.09	0.08	0.93	0.13
Three Months	31.8	65.6	18.6	38.2	324	10.1	0.41	0.18	0.58	0.07	0.40	0.11
Western	39.5	70.0	24.7	13.8	333	—	0.49	0.28	0.56	0.08	0.53	0.10
Toni	21.3	64.5	22.8	84	248	—	0.79	0.18	0.39	0.09	0.71	0.10
TIS 2498	17.7	50.0	21.2	41.8	322	11.2	0.42	0.15	1.03	0.09	0.28	0.08
Nawaro	34.7	53.6	21.4	70.5	166	12.9	0.57	0.14	0.63	0.19	1.07	0.11
Western Province	40.8	49.0	27.1	26.1	317	16.7	0.66	0.19	0.35	0.16	0.66	0.12
Teomo	24.6	50.5	18.4	42.8	247	10.0	0.48	0.12	0.34	0.08	0.47	0.09
Vaka	31.6	52.4	31.4	37.9	382	12.8	0.48	0.08	0.40	0.06	0.52	0.10
158a	39.1	63.8	28.3	78.4	179	18.8	0.69	0.18	0.47	0.10	0.49	0.07
40	28.4	52.2	24.5	53.2	237	11.4	0.30	0.19	1.89	0.05	0.44	0.10
108	57.0	48.0	27.7	34.0	129	15.0	0.37	0.18	0.34	0.12	0.67	0.08
107	56.7	68.4	21.2	34.4	335	17.0	0.42	0.23	0.40	0.17	0.84	0.13
139	41.2	41.0	27.5	48.6	224	11.3	0.24	0.15	0.27	0.06	1.14	0.09
Lai	29.9	59.6	21.2	32.9	364	12.5	0.30	0.22	0.64	0.08	0.37	0.11
Mean	35.0	56.6	23.7	45.0	271	13.2	0.50	0.17	0.63	0.10	0.64	0.10
SD	11.2	8.6	4.0	19.3	76	2.8	0.19	0.05	0.43	0.04	0.26	0.02
Tonga (see Table 4.1)	44.5	29.4	35.7	72.5	243	13.0	0.70	0.22	0.29	0.26	0.24	0.14

[a] Results for the first six Solomon Islands cultivars are the mean of analyses on two different tubers; for Tonga, results are the mean of five values on three different cultivars (see Table 4.1).

Table A.9. Vitamin contents of sweet potato (mg/100 g fresh weight).[a]

	PNG	*Solomon Islands*	*Tonga*	*Number of cultivars per country*
Vitamin A	0.014	0.008	—	3
(ret. + β-carotene/6)	(0.006)	(0.002)	—	
Thiamin	0.085	0.073	0.099	3
	(0.030)	(0.020)	(0.018)	
Riboflavin	0.025	0.041	0.027	3
	(0.002)	(0.013)	(0.006)	
Nicotinic acid	0.77	0.66	0.38	3
	(0.10)	(0.12)	(0.09)	
Pot. nic. acid =	—	0.32	—	—
Trp/60		(0.08)		
Ascorbic acid (AA)	—	14.3	—	10
		(5.1)		
Dehydroascorbic acid (DAA)	—	9.2	—	10
		(2.1)		
Total vitamin C	—	22.5	—	10
= AA + DAA		(6.0)		

[a] Mean values of 3–10 cultivars given with standard deviations in parentheses; no vitamin D_2 present (see Bradbury and Singh 1986a,b; Singh and Bradbury 1988).

Table A.10. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for sweet potato from Solomon Islands and Tonga.

	Solomon Islands cultivars (Table A.1)					*Tongan cultivars (Table A.3)*				
Amino acid	*TIS 2498*	*108*	*107*	*139*	*Mean values*	*Hawaii*	*Tongamai*	*Halasika*	*Melefakahua*	*Mean values*
Alanine	305	327	313	273	—	293	237	302	196	—
Arginine	244	248	392	209	—	177	253	189	127	—
Aspartic acid	785	1304	751	849	—	885	898	785	584	—
Cystine (Cys)	226	141	85	221	—	69	70	58	55	—
Glutamic acid	534	462	375	415	—	454	476	680	429	—
Glycine	265	214	199	197	—	276	211	301	234	—
Histidine	78	147	203	96	—	84	—	91	69	—
Isoleucine	242	211	183	159	—	198	227	241	154	—
Leucine	349	354	331	309	—	256	345	358	266	—
Lysine	350	185	262	210	—	227	227	224	175	—
Methionine (Met)	123	76	115	120	—	57	89	122	74	—
Phenylalanine (Phe)	274	282	303	242	—	191	426	264	129	—
Proline	223	235	198	223	—	217	262	175	152	—
Serine	242	233	287	273	—	296	255	363	227	—
Threonine	278	287	222	217	—	359	249	328	246	—
Tryptophan	92	59	67	55	—	—	—	—	—	—
Tyrosine (Tyr)	132	131	237	120	—	121	145	127	197	—
Valine	290	304	327	300	—	337	275	300	256	—
Amino Acid Scores										
Histidine	66	124	171	81	111(47)	71	—	76	58	68(9)
Cys + Met	224	139	128	219	178(51)	81	102	115	83	95(16)
Isoleucine	138	121	105	91	114(20)	113	130	138	88	117(22)
Leucine	85	86	80	75	82(5)	62	84	87	64	74(13)
Lysine	96	51	72	58	69(20)	63	63	62	48	59(7)
Phe + Tyr	103	105	137	92	109(19)	79	145	99	83	102(30)
Threonine	131	135	104	102	118(17)	169	117	154	115	139(27)
Tryptophan	153	98	112	92	114(27)	—	—	—	—	—
Valine	132	139	149	137	139(7)	154	126	137	117	134(16)
Recovery of Nitrogen (%)	80	60	67	60	67	62	60	66	48	59

Table A.11. Content of organic acid anions, calcium oxalate and calcium (mg/100 g fresh weight) present in sweet potato.

Sample	*Total oxalate*	*Soluble oxalate*	*Calcium oxalate (CaOx)*[a]	*Total calcium*	*Calcium not combined as CaOx*[b]	*Malate*	*Citrate*	*Succinate*
Fiji (Table A.7)								
TIS 3017	40	23	25	38	30	136	58	139
	(19)	(11)				(87)	(28)	(32)
Solomon Islands (Table A.1)								
TIS 2498	78	52	38	22	10	251	156	804
	(26)					(225)	(133)	(448)
Mean of 2	59	38	32	30	20	194	107	472
	(27)	(21)	(9)	(11)	(14)	(81)	(69)	(470)
Solomon Islands (Table A.1)								
Santa Cruz	64	—	—	31	—	137	171	—
	(22)					(56)	(165)	
Three Months	95	—	—	32	—	82	150	—
	(22)						(212)	
Western	147	—	—	40	—	101	20	—
	(40)					(39)	(28)	
Toni	49	—	—	21	—	67	—	—
Nawaro	150	—	—	35	—	136	85	—
U.S.								
Picha (1985)[c]	—	<2	—	—	—	250	210	70
						(90)	(80)	(10)

[a] Calcium oxalate = (total oxalate-soluble oxalate) 128/88.

[b] Calcium not combined as calcium oxalate = total Ca - (40 CaOx/128). This is called free calcium.

[c] Mean of six U.S. cultivars. The low value for soluble oxalate was obtained after treatment of sweet potato with 80% ethanol, which probably did not dissolve all the water-soluble oxalate.

Table A.12. Effect of cooking (boiling and baking) on water-soluble vitamins of sweet potato (mg/100 g fresh weight).[a]

Time of treatment (min)	*Thiamin*	*Riboflavin*	*Nicotinic acid*	*Ascorbic acid (AA)*	*Dehydroascorbic acid (DAA)*	*Total vitamin C (AA + DAA)*
Boiling						
0	0.090	0.024	0.46	12.9	6.3	19.2
10[b]	0.069	0.016	0.37	6.4	4.4	10.8
10[c]	0.080	0.021	0.41	8.6	7.6	16.2
20[b]	0.059	0.013	0.32	3.4	2.9	6.3
20[c]	0.074	0.019	0.39	7.5	8.2	15.7
30[b]	0.035	0.011	0.27	2.2	2.1	4.3
30[c]	0.067	0.019	0.36	4.0	5.7	9.7
Baking						
0	0.090	0.024	0.46	13.0	6.3	19.2
15	0.072	0.019	0.37	9.0	8.1	17.1
30	0.069	0.019	0.36	5.4	5.1	10.5
45	0.064	0.016	0.34	2.9	3.4	6.2

[a] Sweet potato from Tenaru, Solomon Islands, cv hybrid 38.6. Planted 26 July 1984, harvested 7 January 1985; no fertilizer used. Sweet potato was properly cooked after 20 min boiling or 30 min baking.
[b] Water discarded.
[c] Water retained.

Table A.13. Comparison of sweet potato cultivars from different PNG environments.

Sample designation	*Moisture %*	*Energy E_b (kJ/100 g)*	*Protein %*
Poor environment, Kaintiba District, Gulf Province			
Buwang	65.9(2.2)	554	0.80(0.05)
Wanuma	65.7(2.7)	557	0.75(0.11)
Nagama	66.0(3.9)	552	0.52(0.21)
Ekuma	73.0(1.6)	430	0.47(0.10)
Miango	64.2(2.8)	583	0.99(0.22)
Kawape	69.1(2.4)	498	0.49(0.07)
Huyamango	67.2(2.5)	531	0.58(0.04)
Hamba	64.6(2.8)	576	0.73(0.10)
Kapu	70.4(1.3)	475	0.54(0.11)
Mapia	71.0(7.0)	465	0.47(0.19)
Mainua	68.4(3.1)	510	0.41(0.10)
Watuya	68.5(1.7)	508	0.69(0.25)
Mean	67.8(2.7)	520(47)	0.62(0.17)
Popular cultivars from Laloki Research Station[b]			
L39, L136, L250, L291, L293, L303, L318, L390, L391, L392, L437	68.1(4.8)	515	1.51(0.36)
Mean of 164 samples from five countries (Table 3.1)	71.1(2.4)	438(39)	1.43(0.47)

[a] Results are the mean of five analyses from five separate tubers of each cultivar; obtained April 1986.
[b] Cultivars obtained in October 1985. Results were mean of the 11 cultivars for each of which five analyses were made on different tubers.

Table A.14. Composition of taro (*C. esculenta*) corms and suckers from three successive plantings in Fiji.

Sample designation	Yield (t/ha) marketable	Moisture %	Energy (kJ/100 g) E_a	E_b	Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Trypsin inhibitor (TIU/g)
		a			b	e	f	g	c	d			
First Harvest, July 1983[a,b,c]													
Samoa green	14.0	65.6	486	559	2.06	24.5	1.81	2.17	0.14	0.78	22.8	0.99	82
Samoa hybrid	15.2	69.6	415	489	1.50	20.7	1.99	1.96	0.15	0.81	23.0	1.47	8.9
Samoa	11.5	62.5	533	613	1.19	28.3	1.88	1.35	0.05	0.76	18.2	0.52	16.5
Samoa oriori	—	69.0	406	500	1.25	20.3	2.18	1.68	0.13	1.19	32.0	0.45	7.6
Dalo ni Toga	—	75.6	324	385	1.69	15.3	1.96	1.72	0.10	1.26	24.9	0.48	31
Toakula	12.6	63.7	465	592	1.00	28.8	0.91	1.32	0.08	1.10	27.3	0.81	32
Tausala ni Samoa	—	73.7	365	418	2.69	16.4	2.18	1.92	0.15	1.06	24.7	0.48	45
Tausala ni Mumu	—	75.2	329	392	0.88	16.7	1.60	1.87	0.12	1.13	36.4	0.40	46
Vavai dina	—	69.1	414	498	0.94	20.9	2.30	2.19	0.16	1.14	33.3	0.69	0.38
Hawaii	—	59.1	600	672	0.69	32.5	1.82	1.28	0.16	0.83	47.3	0.64	0.55
Mean	—	68.3	434	512	1.39	22.4	1.86	1.75	0.12	1.01	29.0	0.69	27
SD	—	5.6	94	97	0.63	6.3	0.39	0.34	0.04	0.19	8.5	0.33	26
Second Harvest, February 1984[a,c]													
Samoa green	—	62.5	592	613	0.92	33.1	0.62	0.90	0.11	0.74	15.7	0.55	—
		(3.1)			(0.10)	(3.2)	(0.42)	(0.25)	(0.01)	(0.09)	(1.4)	(0.04)	
Samoa	—	61.6	541	628	0.90	29.7	0.98	1.20	0.12	0.76	17.7	0.44	—
		(0.68)			(0.08)	(2.2)	(0.11)	(0.14)	(0.02)	(0.03)	(0.7)	(0.06)	
Toakula	—	64.5	517	578	1.04	27.5	1.73	1.52	0.13	0.67	23.6	0.83	—
		(4.1)			(0.50)	(4.9)	(0.68)	(0.65)	(0.03)	(0.01)	(5.8)	(0.23)	
Tausala ni Samoa	—	65.0	478	569	1.08	26.3	0.65	1.31	0.07	0.81	23.6	0.95	—
		(2.7)			(0.32)	(1.0)	(0.35)	(0.26)	(0.02)	(0.08)	(1.2)	(0.07)	
Vavai dina	—	60.7	585	644	0.96	32.3	0.90	1.23	0.14	0.77	24.5	0.88	—
		(2.7)			(0.25)	(2.2)	(0.50)	(0.12)	(0.01)	(0.03)	(1.1)	(0.04)	
Mean	—	62.9	543	606	0.98	29.8	0.98	1.23	0.10	0.75	21.0	0.73	—
SD	—	1.9	50	32	0.08	3.1	0.45	0.22	0.03	0.05	4.0	0.22	—
Third harvest, August 1984[a,c]													
Samoa green	22.2	64.5	581	578	0.90	32.6	0.57	1.30	0.07	0.76	18.8	0.72	—
Samoa hybrid	26.4	69.1	441	498	0.71	24.4	0.73	0.86	0.08	0.77	16.9	0.32	—
Samoa	19.3	67.5	453	526	0.71	24.8	0.95	1.30	0.08	0.88	22.8	0.33	—

Toakula	14.7	59.1	588	672	1.33	32.0	1.02	1.60	0.12	0.90	28.8	0.64	—
Tausala ni Samoa	9.9	66.0	473	552	1.23	26.0	0.38	1.26	0.10	1.03	27.6	0.52	—
Mean	—	65.2	507	565	0.98	28.0	0.73	1.26	0.09	0.87	23.0	0.51	—
SD	—	3.8	76	67	0.29	4.3	0.26	0.26	0.02	0.11	5.2	0.18	—
Suckers from third harvest													
Samoa hybrid	—	64.4	534	579	0.90	29.7	0.67	1.19	0.09	0.83	14.6	0.33	19.0
Samoa	—	70.7	412	470	0.72	22.7	0.61	1.35	0.12	0.76	12.5	0.39	5.1
Mean	—	67.6	473	525	0.81	26.2	0.64	1.27	0.11	0.80	13.6	0.36	12.1
SD	—	4.5	86	77	0.13	5.0	0.04	0.11	0.02	0.05	1.4	0.04	9.8

[a] First crop planted August 1982, harvested July 1983; second (dry season) crop planted February–June 1983, harvested December 1983–February 1984, irrigated June–July; third crop planted 19 September 1983, harvested 3 August 1984; all grown at Koronivia Research Station (elevation 10 m, rainfall and soil analysis available). Fertilizer used in all crops as follows: P 25 kg/ha at planting, K 100 kg/ha total given at planting and at 3 months, N 150 kg/ha total given as urea at 5, 10 and 15 weeks. Analyses of the first crop were on single corms, for the second crop results are the mean of three corms analysed separately and for the third crop five corms or suckers of each cultivar were bulked together.

[b] Chymotrypsin inhibitor contents of Samoa green, Samoa hybrid and Tausala ni Samoa were zero.

[c] Sum of a + b + c + d + e + f + g for first, second and third harvests are 96.8, 96.7 and 97.1 respectively.

Table A.15. Composition of taro *Colocasia* corms from Suva market.[a]

Sample designation		*Samoa*	*Toakula*	*Mean*[b]
Moisture %	a	65.5 (1.0)	66.2 (2.9)	65.9 (0.49)
Energy kJ/100 g				
E_a		540	519	530 (15)
E_b		561 (17)	549 (50)	555 (8)
Protein %	b	0.97 (0.19)	1.39 (0.20)	1.21 (0.25)
Starch %	e	29.6 (3.4)	27.9 (3.2)	28.8 (1.2)
Sugar %	f	1.12 (0.20)	1.08 (0.26)	1.21 (0.18)
Dietary fibre %	g	1.82 (0.41)	1.08 (0.08)	1.45 (0.52)
Fat %	c	0.07 (0.04)	0.09 (0.02)	0.08 (0.02)
Ash %	d	0.76 (0.09)	0.72 (0.03)	0.74 (0.03)
Calcium (mg/100 g)		15.7 (2.6)	15.0 (1.8)	15.4 (0.5)
Iron (mg/100 g)		0.79 (0.18)	0.81 (0.05)	0.80 (0.01)

[a] Five corms of each cultivar obtained from Suva market, July 1986. Results are the mean of analyses on each corm.
[b] Sum of a + b + c + d + e + f + g = 99.4.

Table A.16. Composition of popular cultivars of taro *Colocasia* from Western Samoa.[a]

Sample designation		*Manua*	*Pa'epa'e*	*Niue*	*Fa'ele'ele*	*Mean*[b]	*SD*
Moisture %	a	72.9	72.2	72.7	67.9	71.4	2.4
		(5.8)	(5.0)	(1.5)	(4.0)		
Energy (kg/100 g)							
E_a		435	430	390	461	429	30
E_b		432	444	435	519	458	41
Protein %	b	1.01	1.15	0.82	0.56	0.89	0.26
		(0.26)	(0.51)	(0.29)	(0.07)		
Starch %	e	23.8	23.8	21.8	26.0	23.9	1.7
		(5.8)	(5.0)	(1.8)	(3.7)		
Sugar %	f	0.66	0.29	0.21	0.44	0.40	0.20
		(0.35)	(0.24)	(0.13)	(0.03)		
Dietary fibre %	g	1.28	1.28	1.25	1.11	1.23	0.08
		(0.22)	(0.30)	(0.09)	(0.06)		
Fat %	c	0.10	0.06	0.05	0.06	0.07	0.02
		(0.03)	(0.02)	(0.03)	(0.03)		
Ash %	d	0.57	0.72	0.84	0.85	0.75	0.13
		(0.08)	(0.17)	(0.14)	(0.13)		
Calcium (mg/100 g)		18.6	33.4	18.0	33.2	25.8	8.7
		(5.0)	(8.9)	(3.6)	(1.1)		
Iron (mg/100 g)		0.29	0.38	0.41	0.44	0.38	0.06
		(0.07)	(0.11)	(0.05)	(0.06)		
Trypsin Inhibitor (TIU/g)		zero	26.4	2.5	6.3	8.8	2.0

[a] Samples obtained April 1984. Cultivar Niue accounts for about 75% of total production and Manua and Pa'epa'e are also very popular. Five corms of each of the first three cultivars were analysed and the results averaged, and two corms of the last cultivar.

[b] Sum of a + b + c + d + e + f + g = 98.6.

Table A.17. Taro *Colocasia* breeding lines from Solomon Islands.[a]

Sample designation	*Yield (t/ha)*	*Moisture %*	*Energy (kJ/100 g)* E_a	E_b	*Crude protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Iron (mg/100 g)*	*Trypsin inhibitor (TIU/g)*
		a			*b*	*e*	*f*	*g*	*c*	*d*			
Akalomamale	6.1	66.8	443	538	1.55	23.1	1.29	1.55	0.09	0.72	29.7	0.26	6.8
Luma'abu	10.8	76.6	324	368	0.87	16.7	1.36	1.78	0.11	1.06	59.5	0.46	5.5
Mudi mudi	NA	68.3	463	512	1.03	25.2	0.77	1.09	0.10	1.10	77.5	0.81	6.8
Sasagiha	NA	75.2	331	392	0.66	17.8	0.83	1.34	0.11	1.09	16.2	0.64	3.8
Mean of 4		71.7	390	453	1.03	20.7	1.06	1.44	0.10	0.99	45.7	0.54	5.7
SD		4.9	78	85	0.38	4.4	0.31	0.29	0.01	0.18	27.9	0.24	1.4
PD1 (20)	11.7	89.6	109	142	1.06	4.0	1.26	1.97	0.09	0.67	42.3	0.07	3.5
PD1 (32)	13.1	82.5	189	265	1.71	8.4	0.87	2.55	0.09	1.37	109	0.22	nil
PD11 (5)	11.7	64.5	560	578	2.13	29.6	0.89	1.98	0.17	1.01	20.0	0.21	3.0
PD12 (11)	9.2	86.4	158	197	0.86	6.7	1.62	1.80	0.10	0.78	42.1	0.12	4.0
PD41 (1)	11.6	76.6	331	368	1.35	16.7	1.21	1.62	0.12	0.82	43.0	0.25	26.0
PD41 (4)	10.4	83.1	203	255	0.96	9.8	1.03	1.32	0.08	0.98	37.6	0.14	1.0
PD41 (8)	10.7	76.6	306	368	1.92	14.6	1.30	2.06	0.10	1.22	104	0.18	6.6
PD41 (17)	10.5	87.5	148	178	0.82	5.1	1.34	2.06	0.09	0.67	89.5	0.10	nil
PD51 (9)	8.7	80.6	243	298	1.09	12.1	0.93	1.73	0.11	1.06	33.1	0.38	nil
PD51 (27)	11.7	86.0	134	204	1.08	5.9	0.77	2.78	0.10	1.15	48.0	0.19	4.2
Mean of 14[b]		78.6	282	333	1.22	14.0	1.11	1.83	0.10	0.98	60.8	0.29	5.1
SD		8.0	150	138	0.45	8.7	0.27	0.46	0.02	0.22	33.1	0.22	6.5

[a] Two corms of each cultivar bulked. First four cultivars are common local cultivars, next 10 entries marked PD are first generation back-cross taros. They are resistant to *Phytophthora colocasiae* but the Solomon Islands taste panel described their taste as spongy and they are watery, confirmed by a high moisture content. Cultivars Mudi mudi, and Sasagiha planted 1 March 1984, others planted 11 February 1984, harvested 28 September 1984 at Tenaru, Guadalcanal. Fertiliser 30 kg/ha potassium chloride, 200 kg/ha ammonium sulphate. Low rainfall since June slowed the growth of all taro plants and caused premature senescence. NA = not available.

[b] Sum of a + b + c + d + e + f + g = 97.8.

Table A.18. Taro *Colocasia* edible and non-edible green leaves from Fiji.[a]

Sample designation	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)
		E_a	E_b								
	a			*b*	*e*	*f*	*g*	*c*	*d*		
Dalo ni wai[c]	85.4	128	214	4.32	0.14	1.56	4.38	0.70	1.50	182	0.65
Toakula[b]	86.4	114	197	4.79	0.04	0.52	5.25	0.61	1.55	297	0.64
Tausala ni Mumu[b]	89.5	86	143	2.56	0.09	1.09	3.46	0.58	1.05	157	0.37
Vavai dina[b]	84.5	122	230	4.83	0.04	1.01	4.94	0.61	1.46	114	0.68
Hawaii[b]	83.3	146	216	5.03	0.04	1.81	6.07	0.81	1.52	175	0.68
Samoa hybrid[d]	86.4	89	197	3.86	0.04	0.33	5.29	0.45	1.52	157	0.64
Tausala ni Samoa[d]	82.5	115	265	4.79	0.04	0.66	6.21	0.60	2.11	246	0.79
Vutikoto[d]	84.6	116	228	4.39	0.11	1.29	4.86	0.50	1.83	204	0.61
Samoa[e]	86.0	93	204	3.58	0.04	0.53	4.54	0.64	1.68	126	0.64
Samoa green[c]	85.8	95	208	3.84	0.06	0.40	5.31	0.58	1.59	159	0.52
Mean[f]	85.4	110	210	4.20	0.07	0.92	5.03	0.61	1.58	182	0.62
SD	1.9	19	31	0.76	0.04	0.51	0.81	0.13	0.27	55	0.11

[a] Third crop; for details see Table A.14. Six leaves of each cultivar bulked together. No trypsin inhibitor present in leaves from Tausala ni mumu, Tausala ni Samoa and Samoa.
[b] Edible leaves.
[c] Grown for its leaf.
[d] Generally not edible but sometimes eaten.
[e] Non-edible leaf.
[f] Sum of a + b + c + d + e + f + g = 97.8.

Table A.19. Content of minerals (mg/100 g fresh weight) of taro *Colocasia* corms and leaves from Fiji.

	Ca	*P*	*Mg*	*Na*	*K*	*S*	*Fe*	*Cu*	*Zn*	*Mn*	*Al*	*B*
Corms, First Harvest, (Table A.16)												
Samoa green	21.7	55.3	143	0.98	310	10.1	0.63	0.28	1.5	0.42	0.32	0.07
Samoa hybrid	25.3	44.1	132	3.1	354	7.7	0.58	0.23	1.5	0.42	0.39	0.09
Samoa	21.4	27.8	92.4	4.2	315	6.4	0.28	0.10	0.66	0.34	0.26	0.07
Samoa oriori	22.3	100.2	123	0.51	533	8.2	0.30	0.29	3.6	0.32	0.26	0.10
Dalo ni Toga	45.0	100.8	124	0.53	565	14.0	0.37	0.18	5.5	0.25	0.54	0.11
Toakula	27.7	95.2	69.8	2.8	465	7.3	0.85	0.14	3.6	0.51	0.35	0.08
Tausala ni Samoa	25.2	87.7	127	0.92	498	8.7	0.32	0.27	4.5	0.29	0.30	0.11
Tausala ni Mumu	30.2	71.4	125	0.52	506	7.1	0.15	0.24	7.2	0.26	0.34	0.07
Vavai dina	55.9	90.2	101	2.4	488	6.5	0.43	0.18	6.4	0.37	0.69	0.12
Mean	30.5	74.7	115	1.8	448	8.5	0.43	0.21	3.8	0.35	0.38	0.09
SD	12.0	26.7	23	1.4	96	2.4	0.22	0.07	2.3	0.09	0.14	0.02
Corms (Table 4.2)	15.7	33.4	31.7	3.4	328	5.4	0.79	0.20	0.47	0.14	0.31	0.09
Leaves[a]	182	61.3	90	7.9	487	23.9	0.62	0.15	0.66	4.5	1.83	0.36
	(55)	(7.8)	(28)	(2.9)	(74)	(2.9)	(0.11)	(0.05)	(0.18)	(1.6)	(0.30)	(0.03)

[a] Mean and standard deviations of results from six cultivars from Table A.18.

Table A.20. Vitamin content of taro *Colocasia* corms (mg/100 g fresh weight).[a]

	Source of taro			
	Fiji	*Solomon Islands*	*Western Samoa*	*Mean*
Vitamin A (ret. + β-carotene/6)[b]	0.007	0.007	—	0.007
	(0.002)	(0.001)		
Thiamin	0.035	0.037	0.025	0.032
	(0.013)	(0.022)	(0.006)	(0.006)
Riboflavin	0.034	0.017	0.025	0.025
	(0.007)	(0.006)	(0.006)	(0.009)
Nicotinic acid (Nic.acid)	0.92	0.68	0.67	0.76
	(0.27)	(0.37)	(0.21)	(0.14)
Pot. Nic. Acid = Trp/60[b]	—	0.22	0.16	0.19
		(0.05)	(0.05)	(0.04)
Ascorbic acid (AA)	6.9	—	—	—
Dehydroascorbic acid (DAA)	8.2	—	—	—
Total vitamin C = AA + DAA	15.1	—	—	—
	(11–20)			

[a] Mean values of 3–4 cultivars given with standard deviation in parentheses (range given for vitamin C), no vitamin D_2 present (see Bradbury and Singh 1986 a,b; Singh and Bradbury 1988).

[b] See section 2.17.

Table A.21. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for taro *Colocasia* from Fiji and Western Samoa.

Amino acid	*Samoa green*[a]	*Samoa*[a]	*Toakula*[a]	*Samoa hybrid*[b]	*Samoa oriori*[b]	*Tausala ni mumu*[b]	*Vavai dina*[c]	*Tausala ni Samoa*[c]	*Manua*	*Pa'epa'e*	*Niue*	*Fa'ele'ele*	*Mean*	*SD*
Alanine	257	370	446	340	574	511	342	333	376	367	291	276	—	—
Arginine	297	356	430	232	287	531	263	433	350	426	434	355	—	—
Aspartic acid	559	692	750	553	733	1041	739	794	763	849	724	681	—	—
Cystine (Cys)	126	175	161	70	234	251	74	87	186	210	156	376	—	—
Glutamic acid	603	779	857	808	970	988	928	923	809	740	855	940	—	—
Glycine	211	274	277	233	219	309	282	286	231	297	296	271	—	—
Histidine	97	172	253	89	370	204	105	212	95	117	169	105	—	—
Isoleucine	132	211	189	133	137	150	138	174	193	212	213	243	—	—
Leucine	303	425	402	211	433	529	561	343	343	514	522	422	—	—
Lysine	119	206	350	147	285	385	179	427	165	190	163	274	—	—
Methionine (Met)	48	80	75	43	84	88	50	52	63	54	55	60	—	—
Phenylalanine (Phe)	241	328	352	193	202	395	267	297	317	337	347	273	—	—
Proline	169	252	220	217	314	275	181	262	207	241	190	204	—	—
Serine	211	276	313	224	269	347	275	319	243	309	305	268	—	—
Threonine	133	174	195	118	318	255	223	206	233	221	182	142	—	—
Tryptophan	—	50	97	—	—	85	100	—	—	—	56	125	—	—
Tyrosine (Tyr)	113	171	159	140	131	203	105	120	132	235	151	151	—	—
Valine	199	265	271	196	256	247	195	251	265	289	305	262	—	—
Amino Acid Scores														
Histidine	82	145	213	75	311	171	88	178	80	98	142	88	139	71
S containing (Cys + Met)	112	163	151	72	204	217	79	89	160	169	135	279	153	61
Isoleucine	75	120	107	76	78	85	78	99	110	120	121	138	101	22
Leucine	73	103	97	51	105	128	136	82	83	124	126	102	101	24
Lysine	33	57	96	40	79	106	49	120	45	52	45	75	66	28
Aromatic (Phe + Tyr)	90	127	130	85	87	152	94	106	114	145	126	108	114	23
Threonine	62	82	92	55	149	120	105	97	109	104	85	67	94	26
Tryptophan	—	83	162	—	—	142	167	—	—	—	93	208	143	47
Valine	91	121	124	89	117	113	89	115	121	132	139	120	114	16
% Recovery of N	52	68	77	54	76	83	66	81	64	74	72	68	67	16

[a] Mean of two results from the first and second harvests, see Table A.14.
[b] From first harvest.
[c] From second harvest.

Table A.22. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for taro *Colocasia* leaves from Fiji (see Table A.18).

Amino acid	*Vavai dina*	*Hawaii*	*Samoa*	*Mean*	*SD*
Alanine	182	173	109	—	—
Arginine	212	122	361	—	—
Aspartic acid	620	654	465	—	—
Cystine (Cys)	136	146	177	—	—
Glutamic acid	1933	1418	1094	—	—
Glycine	219	203	60	—	—
Histidine	126	103	76	—	—
Isoleucine	123	121	160	—	—
Leucine	244	251	206	—	—
Lysine	254	227	193	—	—
Methionine (Met)	60	53	36	—	—
Phenylalanine (Phe)	334	202	348	—	—
Proline	148	167	109	—	—
Serine	129	145	115	—	—
Threonine	180	178	146	—	—
Tryptophan	83	—	97	—	—
Tyrosine (Tyr)	107	140	147	—	—
Valine	219	150	193	—	—
Amino Acid Scores					
Histidine	106	86	64	85	21
S-containing (Cys + Met)	126	128	137	130	6
Isoleucine	70	69	91	77	12
Leucine	59	61	50	57	6
Lysine	70	63	53	62	9
Aromatic (Phe + Tyr)	112	87	126	108	20
Threonine	85	84	68	79	10
Tryptophan	138	—	162	150	17
Valine	100	68	88	85	16
% recovery of N	62	53	48	54	7

Table A.23. Content of organic acid anions, calcium oxalate and calcium (mg/100 g fresh weight) in taro *Colocasia* corms, suckers and leaves from Fiji (third harvest).

Sample	*Total oxalate*	*Soluble oxalate*	*Calcium oxalate (CaOx)*[a]	*Total calcium*	*Calcium not combined as CaOx*[b]	*Malate*	*Citrate*	*Succinate*
Corms								
Samoa hybrid	54	34	29	17	8	124	117	204
Samoa green	38	29	13	19	15	58	52	—
Samoa	78	39	57	23	5	131	102	—
Tausala ni Samoa	70	37	48	28	13	114	135	—
Toakulu	84	38	67	29	8	110	103	132
Mean of 5	65	35	43	23	10	107	102	168
	(19)	(4)	(22)	(5)	(4)	(29)	(31)	(51)
Suckers								
Samoa hybrid	61	—	—	15	—	0	0	0
Samoa	59	—	—	13	—	0	0	0
Mean of 2	60	—	—	14	—	0	0	0
	(1)			(1)				
Leaves								
Dalo ni wai[c]	368	—	—	182	—	760	670	—
Hawaii[d]	374	72	439	175	38	700	98	239
Vavai dina[d]	350	132	317	114	15	619	107	317
Toakulu[d]	574	—	—	297	—	480	160	—
Tausala ni mumu[d]	278	—	—	157	—	600	110	—
Samoa hybrid[e]	483	177	445	157	18	451	188	193
Tausala ni Samoa[e]	532	—	—	246	—	680	170	—
Vutikoto[e]	552	—	—	204	—	960	110	—
Samoa green[f]	324	—	—	159	—	390	120	—
Mean of leaves	426	127	400	182	24	627	193	249
	(110)	(53)	(72)	(55)	(13)	(175)	(182)	(63)

[a] Calcium oxalate = (total oxalate − soluble oxalate) 128/88.

[b] Calcium not combined as calcium oxalate = total Ca − (40 CaOx/128) = free calcium.

[c] Grown for its leaf.

[d] Edible leaves.

[e] Generally not edible but sometimes eaten.

[f] Nonedible leaf.

Table A.24. Effect of cooking (boiling and baking) on vitamin content of taro *Colocasia* (mg/100 g fresh weight).[a]

Time of treatment (minutes)	*Thiamin*	*Riboflavin*	*Nicotinic acid*
Boiling			
0	0.042	0.018	1.06
10[b]	0.030	0.015	0.66
10[c]	0.036	0.015	0.90
20[b]	0.018	0.012	0.59
20[c]	0.030	0.015	0.85
30[b]	0.012	0.009	0.47
30[c]	0.027	0.012	0.73
Baking			
0	0.042	0.018	1.06
15	0.033	0.015	0.85
30	0.027	0.015	0.82
45	0.027	0.012	0.69

[a] Taro from Koronivia Research Station, Fiji, cultivar Samoa hybrid, yield 12.6 t/ha, second harvest; see Table A.14. Taro samples were properly cooked after 20 min boiling or 30 min baking.

[b] Water discarded.

[c] Water retained.

Table A.25. Taro (*X. sagittifolium*): three popular cultivars from Tonga.[a]

		Futuna cv	*Maheleuli* cv	*Tea* cv	*Mean*[b]
Moisture %	a	72.6 (3.1)	65.4 (3.5)	66.3 (1.5)	68.1 (3.9)
Energy kJ/100 g					
E_a		399	516	514	476 (72)
E_b		437	562	547	515 (68)
Protein %	b	1.37 (0.19)	1.30 (0.23)	1.65 (0.26)	1.44 (0.19)
Starch %	e	21.1 (3.6)	28.4 (3.4)	27.8 (1.7)	25.7 (4.3)
Sugar %	f	0.73 (0.17)	0.48 (0.08)	0.51 (0.20)	0.57 (0.14)
Dietary fibre %	g	1.20 (0.24)	1.12 (0.21)	1.13 (0.24)	1.15 (0.04)
Fat %	c	0.11 (0.02)	0.13 (0.03)	0.12 (0.03)	0.12 (0.01)
Ash %	d	1.20 (0.09)	1.10 (0.10)	1.06 (0.12)	1.12 (0.07)
Minerals (mg/100 g)					
Ca		5.3 (1.6)	7.1 (1.6)	5.2 (1.2)	5.9 (1.1)
P		44.1 (3.2)	52.0 (6.5)	62.3 (5.4)	52.8 (9.1)
Mg		23.8 (1.6)	27.5 (4.1)	30.2 (1.4)	27.2 (3.2)
Na		6.6 (0.6)	7.8 (0.2)	5.4 (1.2)	6.6 (1.2)
K		548 (82)	546 (19)	504 (52)	533 (25)
S		6.6 (0.5)	8.3 (1.8)	8.9 (0.5)	7.9 (1.2)
Fe		0.43 (0.13)	0.39 (0.04)	0.58 (0.18)	0.47 (0.10)
Cu		0.19 (0.04)	0.19 (0.07)	0.19 (0.01)	0.19
Zn		0.48 (0.10)	0.53 (0.08)	0.54 (0.04)	0.52 (0.03)
Mn		0.13 (0.04)	0.18 (0.03)	0.19 (0.09)	0.17 (0.03)
Al		0.48 (0.17)	0.75 (0.16)	0.37 (0.08)	0.53 (0.20)
B		0.09 (0.03)	0.08 (0.02)	0.10 (0.02)	0.09 (0.01)
Vitamins (mg/100 g)[c]					
Vitamin A (ret. + β-car/6)					0.005 (0.003)
Thiamin		0.028	0.029	0.014	0.024 (0.008)
Riboflavin		0.036	0.036	0.024	0.032 (0.006)
Nicotinic acid		0.61	0.71	1.08	0.80 (0.25)
Pot. Nic. acid = Trp/60		0.34		0.31	0.33 (0.02)
Ascorbic acid (AA)		2.8	5.0	7.2	5.0 (2.2)
Dehydroascorbic acid (DAA)		6.6	12.8	6.5	8.6 (3.7)
Total vitamin C = AA + DAA		9.4	17.8	13.7	13.6 (4.2)
Total oxalate (mg/100 g)		41 (10)	44 (3)	94 (36)	60 (30)
Soluble oxalate (mg/100 g)		35 (12)	28 (3)	69 (37)	44 (22)
Calcium oxalate (CaOx)[d], mg/100 g		9	23	36	23 (14)
Calcium not combined as CaOx[e], mg/100g		3	0	-6	-1 (5)
Malate (mg/100 g)		330 (55)	212 (18)	92 (70)	211 (119)
Citrate (mg/100 g)		318 (15)	355 (38)	270 (34)	314 (43)
Succinate (mg/100 g)		337 (121)	526 (74)	654 (300)	506 (159)
Trypsin inhibitor (TIU/g)[f]		0.6	nil	0.3	0.3 (0.3)

[a] Unless stated otherwise, results are the average of analyses on nine separate edible cormels of each cultivar; the mother corms are not eaten and were not analysed. Futuna is the most popular cultivar, Maheleuli second and Tea the third most popular *Xanthosoma* cultivar grown in Tonga. Planted in same field at Vaini Research Station, Tongatapu, 13 September 1983 and harvested 30 November 1984.

[b] Sum of a + b + c + d + e + f + g = 98.2.

[c] Mean of duplicate analyses on one corm of each cultivar.

[d] Calcium oxalate = (total oxalate - soluble oxalate) 128/88.

[e] Calcium not combined as CaOx = total Ca - (40 CaOx/128) = free calcium.

[f] There was no detectable amount of chymotrypsin inhibitor present.

Table A.26. Taro (*X. sagittifolium*): two cultivars from PNG.[a]

		Cv 1	*Cv 2*	*Mean*[b]	*SD*
Moisture %	a	67.1 (3.2)	64.8 (4.4)	66.0	1.6
Energy kJ/100 g					
E_a		546	525	536	15
E_b		533	573	553	28
Protein %	b	1.72 (0.57)	1.60 (0.52)	1.66	0.08
Starch %	e	29.9 (3.4)	28.8 (4.3)	29.4	0.8
Sugar %	f	0.26 (0.07)	0.28 (0.09)	0.27	0.01
Dietary fibre %	g	0.85 (0.16)	0.79 (0.09)	0.82	0.04
Fat %	c	0.10 (0.04)	0.10 (0.02)	0.10	0.00
Ash %	d	0.99 (0.18)	0.92 (0.25)	0.96	0.05
Ca (mg/100 g)		9.7 (0.7)	12.5 (3.2)	11.1	2.0
Fe (mg/100 g)		0.35 (0.08)	0.31 (0.06)	0.33	0.03

[a] Results are the mean of five analyses on five separate cormels of each cultivar obtained from Finschhafen, PNG, March 1987. The mother corm was not analysed.

[b] Sum of a + b + c + d + e + f + g = 99.2.

Table A.27. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for popular taro (*X. sagittifolium*) cultivars from Tonga.[a]

Amino acid	*Futuna 1*	*Futuna 2*	*Tea 3*	*Tea 6*	*Mean*	*SD*
Alanine	337	395	353	207	—	—
Arginine	483	440	334	233	—	—
Aspartic acid	801	726	727	454	—	—
Cystine	252	253	290	225	—	—
Glutamic acid	939	745	721	483	—	—
Glycine	376	334	284	186	—	—
Histidine	82	129	54	58	—	—
Isoleucine	188	172	152	88	—	—
Leucine	484	343	327	181	—	—
Lysine	292	193	202	138	—	—
Methionine	45	66	39	20	—	—
Phenylalanine	336	389	264	130	—	—
Proline	230	203	184	136	—	—
Serine	394	356	363	212	—	—
Threonine	273	228	196	96	—	—
Tryptophan	—	93	—	71	—	—
Tyrosine	115	235	93	66	—	—
Valine	351	329	288	177	—	—
Amino Acid Scores						
S containing (Cys + Met)	190	204	211	157	191	24
Isoleucine	107	98	87	57	86	25
Leucine	117	83	79	44	81	30
Lysine	80	53	56	38	57	17
Aromatic (Phe + Tyr)	114	158	91	50	103	44
Threonine	128	107	92	45	93	35
Tryptophan	—	155	—	118	137	26
Valine	160	150	132	81	131	35
% Recovery of N	88	74	61	40	66	20

[a] Duplicate analyses were made on two different corms of each cultivar.

Table A.28. Composition of giant taro (*A. macrorrhiza*) popular cultivars from Western Samoa.[a]

Sample designation	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Total oxalate (mg/100 g)	Trypsin inhibitor (TIU/g)	Chymo-trypsin inhibitor (CIU/g)
		E_a	E_b											
	a			*b*	*e*	*f*	*g*	*c*	*d*					
Lau Penitala	75.9	219	380	2.64	8.0	1.99	2.10	0.15	1.04	36.0	2.33	32	387	75
Faitama	71.2	419	462	2.30	20.5	1.67	2.10	0.11	1.06	38.6	0.60	21	232	39
Sega[b]	59.8	622	660	2.56	33.0	0.82	1.72	0.09	0.56	24.8	0.80	43	427	77
Niukini[b]	72.8	406	434	1.96	21.2	0.44	1.36	0.15	0.78	18.0	0.45	28	198	39
	(3.8)			(0.4)	(4.0)	(0.19)	(0.04)		(0.03)	(3)	(0.02)	—	(36)	(8)
Toga[b]	72.6	389	437	1.61	20.0	1.11	1.66	0.11	1.01	23.3	0.46	28	145	31
	(1.8)			(0.23)	(2.3)	(0.7)	(0.14)	(0.03)	(0.21)	(3.9)	(0.04)	(15)	(37)	(10)
Fui	71.2	—	462	3.25	—	1.38	—	0.16	1.00	—	0.62	—	643	78
Mean[c]	70.6	411	473	2.39	20.5	1.24	1.79	0.13	0.91	28.1	0.88	30	339	57
SD	5.6	155	97	0.57	9.6	0.57	0.32	0.03	0.20	8.8	0.72	8	185	22

[a] All corms were obtained from farmers' fields or from the market, January 1984. Niu Kini mean of results from two corms, Toga mean of results from four corms. Results for organic acid anions other than oxalate given in Table 3.7.

[b] These corms were 6 months old from same farmer's field at Sa'anapu.

[c] Sum of a + b + c + d + e + f + g = 97.6.

Table A.29. Composition of giant taro (*A. macrorrhiza*) cultivars from Western Samoa.[a]

Sample designation		*Moisture %*	*Energy (kJ/100 g)* E_a	E_b	*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Total calcium (mg/100 g)*	*Iron (mg/100 g)*	*Trypsin inhibitor (TIU/g)*	*Total oxalate (mg/100 g)*	*Soluble oxalate (mg/100 g)*	*Calcium oxalate[e] (mg/100 g)*	*Free calcium[e] (mg/100 g)*	*Malate (mg/100 g)*	*Citrate (mg/100 g)*	*Succinate (mg/100 g)*
		a			b	e	f	g	c	d										
Toga	1[b]	64.5 (0.2)	546	578	3.73 (0.57)	27.4 (1.7)	0.89 (0.30)	1.73 (0.28)	0.10	0.55 (0.09)	22.5	0.87 (0.18)	303 (67)	69	12	83	-3	132	190	—
Toga	2[c]	75.3 (5.7)	388	390	2.14 (0.78)	20.0 (4.6)	0.64 (0.44)	1.10 (0.09)	0.06	0.58 (0.01)	20.0 (5.7)	0.41 (0.07)	160 (57)	38	7	45	6	701	69	—
Toga	3[d]	66.3 (1.8)	497	547	3.30 (0.50)	24.6 (2.2)	1.27 (0.05)	1.61 (0.23)	0.06	0.57 (0.23)	25.7 (2.5)	0.74 (0.08)	202 (36)	36 (14)	—	—	—	—	—	—
Laufola	2[b]	74.4 (0.6)	348	406	1.30 (0.14)	18.2 (2.8)	0.81 (0.10)	1.90 (0.06)	0.09	0.68 (0.06)	30.6 (1.4)	0.72 (0.11)	39 (25)	43 (9)	31 (4)	17	25	285 (40)	295 (36)	150
Niukini	1[c]	70.0 (7.7)	415	482	2.89 (0.50)	20.6 (6.5)	0.81 (0.16)	1.81 (0.05)	0.07	0.86 (0.01)	26.2 (2.8)	0.79 (0.17)	156 (77)	81 (73)	—	—	—	—	—	—
Niukini	2[d]	68.7 (4.7)	499	505	3.79 (1.19)	24.6 (4.4)	0.86 (0.13)	1.22 (0.42)	0.06	0.82 (0.06)	22.3 (3.8)	0.87 (0.25)	327 (89)	29	19	15	18	485	550	472
Fui	1[c]	71.4 (0.6)	400	458	3.21 (0.33)	19.2 (0.2)	0.90 (0.4)	1.44 (0.08)	0.07	0.99 (0.17)	31 (2.1)	0.89 (0.04)	274 (16)	32 (6)	17 (3)	22	24	163 (47)	247 (82)	454 (174)
Sega	1[c]	72.2 (2.6)	390	444	2.91 (0.27)	18.6 (2.1)	1.26 (0.08)	1.15 (0.07)	0.08	0.67 (0.08)	21.8 (0.7)	0.98 (0.03)	251 (17)	16 (4)	10 (1)	9	19	168 (88)	127 (51)	405 (88)
Uli	1[c]	71.3	388	460	1.18	19.9	1.66	1.88	0.09	0.65	36.4	1.25	74	65	20	65	16	306	191	770
Mean[f]		70.4	430	474	2.72	21.4	1.01	1.43	0.08	0.71	26.3	0.83	198	45	17	37	15	320	238	450
SD		3.8	70	61	0.97	3.4	0.32	0.36	0.02	0.15	5.4	0.23	100	21	8	28	10	207	156	221

[a] All cultivars obtained February 1985 from farmers' fields unless stated otherwise, each result is mean from two corms, except Uli which is from a single corm. Results for minerals other than Ca and Fe are averages over six cultivars as follows: P 44(18), Mg 52(23), Na 30(19), K 267(114), S 11.9(3.3), Cu 0.07(0.04), Zn 1.51(0.56), Mn 0.62(0.30), Al 0.36(0.16), B 0.10(0.02). Cultivars Niu Kini and Toga are the most popular and together would account for about 75% of production.

[b] Harvested from same field of farmer at Tanumalala, 3 years old.

[c] Harvested from same field of farmer in Sa'anapua, all 17 months old.

[d] Grown in same plot at Experiment Station, Alafua, harvested 14 months, 9 days after planting.

[e] Calculated as shown in section 2.6.

[f] Sum of a + b + c + d + e + f + g = 97.8

Table A.30. Composition of giant taro (*A. macrorrhiza*) commonly grown cultivars from Tonga.[a]

		Tuu *cv*	*Tea* *cv*	*Fohenga* *cv*	*Mean*[b]	*SD*
Moisture %	a	75.9	69.5	64.3	69.9	5.8
		(2.6)	(2.8)	(3.1)		
Energy (kJ/100 g)						
E_a		296	443	519	419	113
E_b		381	491	582	485	101
Protein %	b	0.50	1.67	1.88	1.35	0.74
		(0.11)	(0.28)	(0.51)		
Starch %	e	16.2	23.7	27.6	22.5	5.8
		(0.8)	(2.7)	(2.6)		
Sugar %	f	0.45	0.58	0.88	0.64	0.22
		(0.05)	(0.14)	(0.13)		
Dietary fibre %	g	2.31	1.99	2.73	2.34	0.37
		(0.18)	(0.12)	(0.39)		
Fat %	c	0.10	0.09	0.09	0.09	0.01
		(0.02)	(0.05)	(0.03)		
Ash %	d	1.23	1.10	1.07	1.13	0.09
		(0.18)	(0.08)	(0.09)		
Calcium (mg/100 g)		38.7	78.0	64.3	60.3	20
		(6.7)	(24.3)	(12.9)		
Iron (mg/100 g)		0.54	0.85	0.99	0.79	0.23
		(0.03)	(0.18)	(0.08)		

[a] Results are the mean of analyses on three corms of Tea (most common cultivar in Tonga) and Fohenga, and two corms of Tuu. All samples were 2 years old, harvested at flowering (December 1984) from same farmer's field near Vaini Research Station, Tongatapu.

[b] Sum of a + b + c + d + e + f + g = 98.0.

Table A.31. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for giant taro (*A. macrorrhiza*) from Western Samoa.[a]

Amino acid	*Lau Penitala cv*	*Faitama cv*	*Sega cv*	*Toga cv*	*Mean*	*SD*
Alanine	228	265	260	249	—	—
Arginine	526	315	311	337	—	—
Aspartic acid	643	737	682	707	—	—
Cystine (Cys)	168	98	227	207	—	—
Glutamic acid	657	821	617	661	—	—
Glycine	323	380	320	339	—	—
Histidine	123	106	96	107	—	—
Isoleucine	149	138	181	180	—	—
Leucine	295	455	424	418	—	—
Lysine	235	217	264	215	—	—
Methionine (Met)	68	55	83	70	—	—
Phenylalanine (Phe)	204	200	262	257	—	—
Proline	253	231	240	343	—	—
Serine	263	306	290	253	—	—
Threonine	199	181	290	303	—	—
Tryptophan	—	98	72	67	—	—
Tyrosine (Tyr)	155	150	180	192	—	—
Valine	265	279	297	278	—	—
Amino Acid Scores						
Histidine	103	89	81	90	91	9
S-containing (Cys + Met)	151	98	199	178	157	44
Isoleucine	85	79	103	103	93	12
Leucine	71	110	103	101	96	17
Lysine	65	60	73	59	64	6
Aromatic (Phe + Tyr)	91	89	112	114	102	13
Threonine	93	85	136	142	114	29
Tryptophan	—	163	120	112	132	27
Valine	121	127	136	127	128	6
% Recovery of N	70	65	66	66	67	2

[a] Samples obtained January 1984; other data given in Table A.28.

Table A.32. Effect of cooking (boiling and baking) on the vitamin content (mg/100 g) of giant taro (*A. macrorrhiza*).[a]

Time of treatment (min)	*Thiamin*	*Riboflavin*	*Nicotinic acid*	*Ascorbic acid (AA)*	*Dehydroascorbic acid (DAA)*	*Total vitamin C (AA + DAA)*
Boiling						
0	0.040	0.022	0.67	11.5	8.4	19.9
10[b]	0.031	0.019	0.44	5.5	4.7	10.2
10[c]	0.033	0.019	0.55	8.0	9.4	17.4
20[b]	0.025	0.015	0.38	3.9	3.9	7.8
20[c]	0.033	0.019	0.46	6.4	7.9	14.3
30[b]	0.015	0.012	0.36	2.2	2.3	4.5
30[c]	0.028	0.015	0.46	4.1	6.4	10.5
Baking						
0	0.040	0.022	0.67	11.5	8.4	19.9
15	0.033	0.019	0.52	7.2	6.3	13.5
30	0.031	0.019	0.47	4.8	4.2	9.0
45	0.025	0.015	0.45	2.6	2.2	4.8

[a] Giant taro corm from Western Samoa, February 1985, cultivar Niu Kini, age 14-17 months.
[b] Water discarded.
[c] Cooking water retained.

Table A.33. Giant swamp taro (*C. chamissonis*) from Kiribati.[a]

Sample designation		*Age of corm*	*Moisture %*	*Energy (kJ/100 g)* E_a	E_b	*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Iron (mg/100 g)*	*Total oxalate (mg/100 g)*	*Trypsin inhibitor (TIU/g)*[b]
Ikaraoi Kairoro	a	1–2	84.4	184	232	0.60	8.1	1.97	2.18	0.10	0.57	86	0.37	100	6.6
			(1.3)			(0.22)	(0.5)	(0.39)	(0.19)	(0.01)	(0.01)	(36)	(0.06)		(6.9)
	b	3–4	82.8	206	260	0.92	10.4	0.57	2.04	0.11	0.63	129	0.54	187	—
			(0.5)			(0.17)	(0.4)	(0.04)	(0.45)	(0.02)	(0.07)	(54)	(0.06)	(80)	
Atimainiku	a	1	79.5	268	317	0.19	14.0	1.10	2.40	0.21	0.68	67	0.34	380	<0.2
	b	2–2.5	81.9	209	276	0.57	11.2	0.34	2.38	0.11	0.58	185	0.16	330	—
			(3.6)			(0.01)	(2.8)	(0.04)	(0.49)	(0.04)	(0.11)	(43)	(0.04)	(85)	
Ikaraoi Ikauraura	a	1.5	79.2	250	323	0.63	12.9	0.97	2.35	0.13	0.55	162	0.48	140	0.41
	b	2–2.5	72.4	369	441	0.49	19.9	0.96	2.94	0.17	1.20	577	0.47	725	—
			(5.6)			(0.11)	(0.01)	(0.09)	(0.06)	(0.02)	(0.04)	(46)	(0.08)		
Katutu Uraura	a	0.75	76.1	304	376	0.81	14.9	1.95	2.49	0.12	0.87	243	0.62	—	4.0
	b	2–2.5	81.4	—	284	0.39	—	0.44	—	0.14	0.80	246	0.24	—	—
			(0.07)							(0.03)	(0.01)	(117)	(0.02)		
Katuta Kairoro	a	0.75	77.7	283	349	0.31	15.1	0.76	2.39	0.21	0.93	383	0.96	450	<0.2
Ikaraoi natutebubua	a	2	79.0	287	326	0.75	14.9	0.96	2.03	0.16	0.56	116	0.40	90	3.4
Mean (SD)		—	79.4	262	318	0.50	13.5	1.06	2.36	0.14	0.74	219	0.46	300	2.5
			(3.5)	(60)	(61)	(0.23)	(3.6)	(0.56)	(0.27)	(0.04)	(0.21)	(156)	(0.22)	(218)	(2.6)

[a] January 1984 samples (labelled a in the Table) were small corms of size normally eaten, from same pit from village of Rawannawi on island of Marakei; January 1985 samples (labelled b in the Table) were 2–3 different corms of the same cultivar; results were averaged. Cultivars Atimainiku, Katutu Uraura and Ikaraoi Ikauraura from same pit in Tearinibai, North Tarawa and Ikaraoi Kairoro from pit in Bonriki, South Tarawa. Mean mineral analyses for January 1984 samples are Ca 176(119), P 13.8(2.2), Mg 24.9(3.7), Na 100(24), K 53(13), S 4.0(1.2), Fe 0.53(0.23), Cu 0.09(0.07), Zn 1.02(0.41), Mn 0.22(0.09), Al 1.30(0.54), B 0.08(0.03). Mean values for organic acid anions are given in Table 3.8.

[b] All samples labelled 'a' were tested and found to contain no chymotrypsin inhibitor.

Table A.34. Giant swamp taro (*C. chamissonis*) of commonly grown cultivars from the high island and atoll of Pohnpei State, Federated States of Micronesia.[a]

Sample designation	*Moisture* %	*Energy (kJ/100 g)* E_a	E_b	*Protein* %	*Starch* %	*Sugar* %	*Dietary fibre* %	*Fat* %	*Ash* %	*Total oxalate (mg/100 g)*	*Soluble oxalate (mg/100 g)*	*Calcium oxalate*[c] *(mg/100 g)*	*Free calcium*[c] *(mg/100 g)*	*Malate (mg/100 g)*	*Citrate (mg/100 g)*	*Succinate (mg/100 g)*
	a			*b*	*e*	*f*	*g*	*c*	*d*							
From Pohnpei (high island)																
Simiden	62.5	504	613	0.54	27.3	1.01	2.57	0.18	0.35	50	—	—	—	—	—	—
Nein Alex	74.7	322	401	0.41	16.9	1.14	3.09	0.13	0.64	244	18	329	18	136	78	105
Nukuro	78.7	—	331	0.38	—	0.85	—	0.13	—	160	—	—	—	—	—	—
Pohnengles	66.7	440	540	0.81	23.0	1.22	4.30	0.23	0.54	210	—	—	—	—	—	—
Nein Bob	73.7	346	418	0.26	19.1	0.63	3.31	0.19	0.42	350	—	—	—	—	—	—
From Ngatik (atoll)																
Simiden	72.5	360	439	0.34	19.7	0.87	2.97	0.13	0.57	190	—	—	—	—	—	—
Nein Alex	73.0	367	430	0.30	19.6	1.29	3.07	0.21	0.58	397	90	447	32	—	179	83
Nukuro	82.2	252	270	0.21	13.9	0.60	1.74	0.09	0.39	316	27	420	-20	76	107	232
Pohnengles	74.5	325	404	0.94	16.2	1.74	3.52	0.16	0.76	340	—	—	—	—	—	—
Nein Bob	66.9	449	536	0.31	25.0	0.61	4.16	0.21	0.87	710	—	—	—	—	—	—
Mean[b]	71.9	374	438	0.45	20.1	1.00	3.19	0.17	0.57	297	45	399	10	106	121	140
SD	5.8	80	102	0.24	4.6	0.36	0.78	0.05	0.17	179	39	62	27	42	52	80

[a] Two corms of each sample bulked together. Samples obtained May 1985.
[b] Sum of a + b + c + d + e + f + g = 97.4.
[c] Calculated as shown in section 2.23.

Table A.35. Mineral content (mg/100 g) of giant swamp taro (*C. chamissonis*) from the high island and atoll of Pohnpei, Federated States of Micronesia.[a]

Sample designation	*Ca*	*P*	*Mg*	*Na*	*K*	*Fe*	*Cu*	*Zn*	*Mn*
From Pohnpei (high island)									
Simiden	34	11.7	16.4	26.9	88.9	1.34	0.11	3.22	2.58
Nein Alex	121	10.5	12.5	29.1	167	0.79	0.28	4.43	3.27
Nukuro	116	10.9	25.2	42.3	59.3	0.85	0.26	12.3	2.81
Pohnengles	93	12.5	14.3	30.4	136	2.14	0.13	2.80	1.27
Nein Bob	93	9.5	17.9	31.2	59.3	0.84	0.12	4.3	0.93
Mean	91	11.0	17.3	32.0	102	1.19	0.18	5.41	2.17
SD	35	1.2	4.9	6.0	48	0.58	0.08	3.9	1.0
From Ngatik (atoll)									
Simiden	89	27.9	14.8	68.3	82.5	0.48	0.06	0.37	0.05
Nein Alex	172	15.3	21.1	40.0	45.0	0.81	0.05	0.63	0.22
Nukuro	111	6.3	12.0	36.8	30.9	0.23	0.01	0.77	0.09
Pohnengles	166	41.8	26.3	77.3	83.0	0.67	0.18	4.56	0.09
Nein Bob	257	26.8	15.2	60.0	62.0	0.70	0.14	1.48	0.24
Mean	199	23.6	17.9	56.5	60.7	0.58	0.09	1.56	0.14
SD	65	13.5	5.8	17.6	23	0.23	0.07	1.7	0.09

[a] Samples obtained May 1985; see Table A.34. All results obtained by inductively coupled plasma technique. Results for S, Al and B showed no change between mainland and atoll and hence have been omitted; averages are given in Table 3.8.

Table A.36. Amino acid analyses (mg amino acid/g N sample) and scores for giant swamp taro (*C. chamissonis*) from Kiribati.[a]

Amino acid	*Ikaraoi Natutebubua cv*	*Katuta Uraura*[b] *cv*	*Ikaraoi Kairoro cv*	*Mean*	*SD*
Alanine	287	320	458	—	—
Arginine	215	186	271	—	—
Aspartic acid	503	745	753	—	—
Cystine (Cys)	—	123	139	—	—
Glutamic acid	614	707	1005	—	—
Glycine	276	261	324	—	—
Histidine	127	83	145	—	—
Isoleucine	169	194	212	—	—
Leucine	302	388	412	—	—
Lysine	164	178	397	—	—
Methionine (Met)	41	149	40	—	—
Phenylalanine (Phe)	199	184	220	—	—
Proline	134	218	322	—	—
Serine	177	242	307	—	—
Threonine	196	179	281	—	—
Tryptophan	55[c]	49	21	—	—
Tyrosine (Tyr)	178	129	165	—	—
Valine	285	219	309	—	—
Amino Acid Scores					
Histidine	107	94	122	107	14
S containing (Cys + Met)	—	138	115	127	16
Isoleucine	97	103	121	107	12
Leucine	73	87	100	87	14
Lysine	45	56	109	70	34
Aromatic (Phe + Tyr)	96	95	98	96	2
Threonine	92	91	132	105	23
Tryptophan	92	82	35	70	30
Valine	130	110	141	127	16
% Recovery of N	52	60	74	62	11

[a] Samples arrived January 1984; for other results see Table A.33.
[b] Mean value of results on two different hydrolysates.
[c] This tryptophan analysis obtained on cv Nein Alex from Pohnpei (high island), Table A.34.

Table A.37. Yam (*D. alata*) popular cultivars from East Sepik Province of Papua New Guinea.[a]

Sample designation	*Yield (t/ha) fresh weight*[b]	*Moisture %*	*Energy (kJ/100 g)*		*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Total oxalate (mg/100 g)*	*Mole ratio Ox/Ca*[c]	*Trypsin inhibitor (TIU/g)*
			E_a	E_b										
		a			*b*	*e*	*f*	*g*	*c*	*d*				
Takua Kupmi	28.9 (4.4)	80.8	277	294	1.00	14.5	0.66	0.79	0.06	0.68	4.5	19.2	1.94	—
Kpmora	28.9 (6.8)	78.9	312	327	1.31	15.8	1.24	0.94	0.06	0.96	3.7	24.2	2.97	0.7
Du Kupmi	49.8	76.2	392	374	1.56	20.9	0.55	1.33	0.07	0.74	5.6	—	—	0.8
Takua Yaimbi	13.0 (1.9)	83.4	244	249	1.19	12.7	0.33	1.17	0.08	0.56	7.7	3.8	0.22	0.2
Tolai	43.3 (5.7)	83.8	248	242	1.06	13.1	0.25	0.95	0.07	0.68	5.9	21.9	1.69	0.4
Yavovi	26.7 (2.6)	75.2	378	392	2.00	18.5	1.59	1.95	0.09	0.90	6.8	6.1	0.41	0.7
Mean[d]	—	78.6	309	313	1.35	15.9	0.77	1.19	0.07	0.75	5.7	15.0	1.45	0.56
SD	—	4.0	66	63	0.37	3.4	0.53	0.42	0.01	0.15	1.5	9.4	1.14	0.25

[a] Samples harvested in August 1984. Mineral analyses with standard deviations in parentheses are Ca 5.7(1.5), P 32(7), Mg 17.7(3.5), Na 2.34(0.72), K 312(159), S 9.8(2.3), Fe 0.14(0.03), Cu 0.14(0.04), Zn 0.36(0.10), Mn 0.02(0.01), Al 0.10(0.04), B 0.09(0.03). Mean results for organic acid anions given in Table 3.10.

[b] Standard error of mean given in parentheses.

[c] Mole ratio Ox/Ca = (oxalate content) 40/(Ca content) 88.

[d] Sum of a + b + c + d + e + f + g = 98.6.

Table A.38. Yam (*D. alata*) commonly grown cultivars from Solomon Islands.[a]

Sample designation	Yield (t/ha) total weight	Acceptance rating	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Total oxalate (mg/100 g)	Mole ratio Ox/Ca
				E_a	E_b										
			a			*b*	*e*	*f*	*g*	*c*	*d*				
WSH 9a[b]	24.0	NT[c]	69.6	464	489	2.75	22.7	1.74	2.72	0.10	0.94	15.0	0.75	39.0	1.18
UL 5[b]	16.6	good	74.2	396	409	3.13	19.1	0.94	2.83	0.08	0.89	6.8	0.35	—	—
K	10.2	good	79.2	322	322	2.38	15.3	1.19	1.75	0.06	0.77	7.1	0.54	—	—
GU 144[b]	10.2	excellent	75.3	376	390	2.66	17.6	1.73	3.33	0.12	0.82	8.0	0.36	—	—
GU 147[b]	13.6	NT	79.1	309	324	2.38	14.5	1.12	1.53	0.11	0.69	5.0	0.56	20.9	1.90
A 172	46.9	NT	80.3	320	303	4.19	13.4	1.03	2.13	0.11	0.88	5.6	0.63	—	—
V 7[b]	14.8	excellent	72.7	415	435	3.56	19.2	1.53	2.37	0.10	0.87	9.0	0.53	6.5	0.33
Toki	3.3	excellent	73.9	400	414	3.38	18.3	1.80	2.22	0.09	1.16	10.1	0.39	14.5	0.65
Mean[d]	—	—	75.5	375	386	3.05	17.5	1.39	2.36	0.10	0.88	8.3	0.51	20.2	1.02
SD	—	—	3.7	56	65	0.63	3.1	0.35	0.59	0.02	0.14	3.2	0.14	13.8	0.69

[a] Three tubers of local cultivars of each type bulked for analysis. Planted 9 November 1983, harvested 2 July 1984 at Tenaru Research Station. Fertilizer, single dressing at emergence: 100 kg/ha of ammonium sulphate and 150 kg/ha potash. Mean results for organic acid anions in Table 3.10.

[b] These yams are considered to be some of the best in Solomon Islands, because of resistance to anthracnose disease.

[c] NT = not tested.

[d] Sum of a + b + c + d + e + f + g = 100.8.

Table A.39. Yam (*D. alata*) most popular cultivars from Western Samoa.[a]

		Da 10 *cv*	*Da 20* *cv*	*Mean*[b]	*SD*
Moisture %	a	76.6 (1.2)	78.7 (3.6)	77.7	1.5
Energy (kJ/100 g)					
E_a		386	303	345	64
E_b		368	331	350	26
Protein %	b	1.78 (0.39)	2.29 (0.40)	2.04	0.36
Starch %	e	18.6 (2.1)	14.7 (2.7)	16.7	3.0
Sugar %	f	1.01 (0.27)	0.82 (0.39)	0.94	0.17
Dietary fibre %	g	1.56 (0.44)	2.57 (0.96)	2.07	0.71
Fat %	c	0.06 (0.05)	0.05 (0.01)	0.06	0.01
Ash %	d	0.75 (0.03)	0.66 (0.09)	0.71	0.06
Calcium (mg/100 g)		6.0 (1.2)	15.4 (6.0)	10.7	6.7
Iron (mg/100 g)		0.65 (0.39)	1.64 (0.84)	1.15	0.70

[a] Grown at University of South Pacific School of Agriculture, Alafua, in same plot, 1 × 1 m spacing, staked, fertilised 11 November 1985 with 60 ml of 12-5-20 per plant, rainfall ~3000 mm/year, planted 20 October 1985, harvested 10 July 1986; results are the mean from analysis of five tubers of each cultivar; full mineral analyses in Table 3.10.

[b] Sum of a + b + c + d + e + f + g = 100.2.

Table A.40. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for yam (*D. alata*) from PNG and Solomon Islands.

	PNG (Table A.37)				Solomon Islands (Table A.38)					
Amino acid	*Takua Kupmi*	*Kpmora*	*Du Kupmi*	*Tolai*	*A172*	*GU147*	*V7*	*Toki*	*Mean*	*SD*
Alanine	351	244	342	499	184	235	238	259	—	—
Arginine	356	444	494	445	694	488	530	731	—	—
Aspartic acid	830	985	969	1146	612	755	637	666	—	—
Cystine (Cys)	155	130	98	115	62	109	91	66	—	—
Glutamic acid	1104	1261	1156	1246	699	1075	1172	828	—	—
Glycine	243	214	274	362	163	232	193	233	—	—
Histidine	123	147	163	169	95	—	144	127	—	—
Isoleucine	227	183	294	252	158	196	199	240	—	—
Leucine	490	284	572	576	315	395	390	483	—	—
Lysine	231	257	317	297	205	276	256	221	—	—
Methionine (Met)	95	63	84	65	43	45	63	77	—	—
Phenylalanine (Phe)	369	304	389	455	220	284	279	230	—	—
Proline	276	239	294	261	164	227	191	239	—	—
Serine	303	353	395	483	236	256	288	316	—	—
Threonine	181	310	258	240	148	175	147	189	—	—
Tryptophan	69	—	89	—	46	84	79	—	—	—
Tyrosine (Tyr)	294	199	207	164	105	101	108	125	—	—
Valine	284	226	323	360	194	229	241	260	—	—
Amino Acid Scores										
Histidine	103	124	137	142	80	—	121	107	116	21
S-containing (Cys + Met)	160	124	117	115	67	99	99	92	109	27
Isoleucine	130	105	168	144	90	112	114	137	125	25
Leucine	119	69	138	139	76	67	62	54	91	35
Lysine	64	71	87	82	56	76	71	61	71	11
Aromatic (Phe + Tyr)	168	128	151	157	82	98	98	90	122	34
Threonine	85	146	121	113	69	82	69	89	97	27
Tryptophan	115	—	148	—	77	140	132	—	122	28
Valine	130	103	147	164	89	105	110	119	121	25
% Recovery of N	78	77	88	93	65	68	70	79	77	10

Table A.41. Yam (*D. esculenta*): selections from Solomon Islands.[a]

Sample designation	Yield (t/ha) total	Culinary/ taste rating	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Trypsin inhibitor (TIU/g)	Chymotrypsin inhibitor (CIU/g)
				E_a	E_b										
			a			b	e	f	g	c	d				
NGP4	58.7	very good	76.5	354	369	2.18	18.1	0.51	0.85	0.04	0.87	3.0	1.85	0	—
			(4.4)			(0.54)	(3.2)	(0.22)	(0.10)	(0.02)	(0.08)	(1.7)	(1.9)		
NGP4	—	—	75.6	395	385	2.47	19.4	1.40	0.83	0.04	0.90	7.1	0.49	0	—
			(4.9)			(0.08)	(1.6)	(0.26)	(0.08)	(0.01)	(0.08)	(1.9)	(0.04)		
RFP1	56.0	fair	72.9	407	432	2.22	20.8	0.94	0.95	0.02	0.90	5.8	0.55	0	0
			(5.7)			(0.28)	(4.2)	(0.01)	(0.32)	(0.02)	(0.19)	(2.0)	(0.15)		
GUP5	50.8	good/ fair	72.5	368	439	2.57	18.3	0.76	1.29	0.04	0.94	13.4	0.51	0	0
			(0.6)			(0.16)	(5.8)			(0.03)	(0.08)	(5.4)	(0.03)		
GUP5	—	—	69.5	455	491	2.31	23.4	0.94	1.29	0.08	0.95	4.4	1.28	—	—
			(2.7)			(0.13)	(1.1)	(0.13)	(0.24)	(0.06)	(0.07)	(0.2)	(1.5)		
NGP8	69.1	good/ fair	75.7	374	383	2.36	18.9	0.78	1.38	0.02	0.92	12.9	1.67	0	0
			(3.1)			(0.35)				(0.02)	(0.02)	(7.7)	(2.0)		
GUP4	58.3	poor	74.4	380	406	2.27	19.4	0.59	1.16	0.04	0.83	7.9	0.44	—	—
			(1.8)			(0.14)	(2.6)	(0.34)	(0.26)	(0.02)	(0.03)	(0.3)	(0.05)		
GUP4	—	—	77.9	334	345	2.02	17.2	0.34	0.96	0.04	0.90	3.9	0.48	—	—
			(1.9)			(0.35)	(2.2)	(0.08)	(0.19)	(0.01)	(0.02)	(0.2)	(0.09)		
Mean[b]	—	—	74.4	383	406	2.30	19.4	0.78	1.09	0.04	0.90	7.3	0.91	0	0
SD	—	—	2.7	35	46	0.17	2.0	0.32	0.22	0.02	0.04	4.0	0.59	—	—

[a] Five common cultivars obtained from Tenaru Research Station October 1983; results are mean of 3–4 analyses on different tubers from the one plant. The two results included from cultivars GUP4 and GUP5 represent results from two different plants. Mean analyses for vitamins and organic acids given in Table 3.11.

[b] Sum of a + b + c + d + e + f + g = 98.9.

Table A.42. Yam (*D. esculenta*) popular cultivars grown at Dodo Creek (Guadalcanal) and Dala (Malaita), Solomon Islands.[a]

	Sample designation						
	NGP3	*Fananiu*	*GUP5*	*GUP7*	*GUP11*	*Mean*	*SD*
Dodo Creek[b]							
Yield (total, t/ha)	31.2	50.0	32.8	50.8	9.4	34.8	17
Culinary rating (taste)	fair	—	good-fair	good-fair	fair	—	—
Moisture %	75.3 (3.1)	78.3 (2.0)	74.7 (1.0)	77.0 (3.3)	73.4 (0.8)	75.7	1.9
Energy (kJ/100 g) Eb	390	338	401	361	423	383	33
Protein %	1.68 (0.35)	1.90 (0.33)	2.12 (0.51)	1.42 (0.22)	1.71 (0.20)	1.77	0.26
Starch %	18.4 (2.5)	15.1 (1.5)	18.5 (1.7)	17.3 (2.6)	20.5 (0.2)	18.0	2.0
Dietary fibre %	1.35 (0.35)	1.11 (0.20)	1.09 (0.05)	1.24 (0.19)	0.95 (0.18)	1.15	0.15
Fat %	0.05 (0.01)	0.03 (0.01)	0.03 (0.01)	0.04 (0.01)	0.04 (0.01)	0.04	0.01
Dala[c]							
Moisture %	69.2 (4.3)	73.1 (5.2)	67.9 (4.4)	73.0 (1.9)	70.3 (3.2)	70.7**	2.3
Energy (kJ/100 g) E_b	496	429	519	430	477	470**	40
Protein %	1.94 (0.38)	2.05 (0.26)	2.42 (0.65)	2.09 (0.58)	1.98 (0.43)	2.10*	0.19
Starch %	23.0 (3.5)	18.9 (3.8)	25.4 (4.5)	21.2 (1.8)	22.4 (2.4)	22.2**	2.5
Dietary fibre %	0.86 (0.11)	1.55 (0.30)	1.17 (0.16)	1.64 (0.01)	1.77 (0.35)	1.40	0.37
Fat %	0.03 (0.01)	0.06 (0.01)	0.07 (0.01)	0.08 (0.02)	0.06 (0.01)	0.06	0.02

[a] Results are the mean of three analyses on three separate tubers of each cultivar. The averaged results at Dodo Creek are compared with those at Dala using Students t-test. Differences shown with one and two asterisks are significant at the 5% level ($P<0.05$) and the 1% level ($P<0.01$) respectively. Mean analyses for minerals and vitamins are given in Table 3.11.

[b] Planted 26 November 1983, harvested 31 July 1984 at Dodo Creek Research Station. Soil was sandy loam, excessively well drained on beach plain, 400 m from sea, elevation 5 m. Fertilizer 200 kg/ha potassium chloride, 300 kg/ha ammonium sulfate. Yields obtained from small unreplicated plots. Light sandy loam cropped with *D. esculenta* the previous year. Rainfall N 130, D 135, J 250, F 212, M 310, A 336, M 110, J 51, J 124 mm, total 1659 mm.

[c] Planted 23 November 1983, harvested 23 July 1984; fertilizer 200 kg/ha potassium chloride, 200 kg/ha ammonium sulfate. Soil was a deep, moderately weathered brown clay over calcareous rock. Rainfall F 246, M 827, A 338, M 209, J 274, J 342, total excluding Nov–Jan = 2236 mm.

Table A.43. Yam (*D. esculenta*) commonly grown cultivars, East Sepik Province, PNG.[a]

Cultivar	Yield (t/ha)[b]	Moisture %	Energy (kJ/100 g) E_a	E_b	Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)
		a			*b*	*e*	*f*	*g*	*c*	*d*		
Saramandi Research Station												
Glame	19.0	77.6	310	350	2.03	15.8	0.31	0.90	0.07	0.83	3.5	0.25
		(0.6)			(0.70)	(2.7)	(0.08)	(0.13)	(0.01)	(0.04)	(0.9)	(0.04)
Mart	14.8	75.1	386	394	2.27	19.9	0.38	0.98	0.07	0.85	5.5	0.34
		(2.4)			(0.31)	(3.1)	(0.23)	(0.21)	(0.04)	(0.03)	(2.4)	(0.04)
Saikidi	27.9	74.6	369	402	2.31	18.9	0.37	1.04	0.07	0.84	3.9	0.36
		(1.9)			(0.53)	(1.6)	(0.19)	(0.12)	(0.03)	(0.20)	(1.1)	(0.13)
Mangilmu	18.0	78.1	307	342	2.21	15.3	0.48	0.97	0.05	0.61	5.4	0.29
		(2.4)			(0.34)	(0.8)	(0.41)	(0.25)	(0.02)	(0.16)	(1.0)	(0.04)
Kuali	—	74.6	—	402	1.68	16.6	—	0.64	—	—	—	—
		(4.3)										
Makow-ka	34.8	78.6	—	333	1.73	16.1	—	0.87	—	—	—	—
		(0.5)			(0.16)	(1.3)		(0.01)				
Mean	22.9	76.4	344	371	2.04	17.1	0.39	0.90	0.07	0.78	4.6	0.31
SD	8.2	1.9	40	32	0.28	1.9	0.07	0.14	0.01	0.12	1.0	0.05
Numango, near Balip Village (Maprik)												
Glame	12.6	71.0	437	465	2.24	23.1	0.18	1.19	0.09	0.71	5.0	0.26
		(5.2)			(0.06)	(5.0)	(0.02)	(0.40)	(0.04)	(0.08)	(0.3)	(0.02)
Mart	13.0	77.8	286	347	2.40	14.0	0.19	0.97	0.09	0.89	9.9	0.23
		(5.0)										
Saikidi	—	78.2	315	340	1.94	16.2	0.27	0.96	0.06	0.89	6.3	0.25
		(2.6)			(0.16)	(2.5)	(0.17)	(0.29)	(0.01)	(0.26)	(0.9)	(0.01)
Mangilmu	12.4	78.5	327	335	1.81	16.9	0.41	0.86	0.06	0.66	3.9	0.24
		(2.1)			(0.08)	(1.6)	(0.26)	(0.17)	(0.02)	(0.09)	(0.4)	(0.01)
Kwarungig	—	81.2	—	288	1.54	13.1	—	1.01	—	0.65	5.4	0.18
		(4.7)			(0.51)	(4.0)		(0.14)		(0.23)	(1.6)	(0.02)
Kamart	15.6	79.5	—	317	2.36	15.5	—	1.04	—	0.86	4.9	0.17
		(0.9)										

Table A.43. Continued.

Cultivar	*Yield (t/ha)*[b]	*Moisture %*	*Energy (kJ/100 g)* E_a	E_b	*Protein %*	*Starch %*	*Sugar %*	*Dietary fibre %*	*Fat %*	*Ash %*	*Calcium (mg/100 g)*	*Iron (mg/100 g)*
		a			*b*	*e*	*f*	*g*	*c*	*d*		
Mean	13.4	77.7	344	349	2.05	16.5	0.26	1.01	0.08	0.78	5.9	0.22
SD	1.5	3.5	70	61	0.34	3.8	0.11	0.11	0.02	0.12	2.1	0.04
Mikau Village (South Wosera)												
Glame	16.6	73.3	385	425	1.98	20.3	0.22	1.01	0.09	0.66	7.7	0.28
		(4.4)			(0.56)	(4.6)	(0.09)	(0.22)	(0.03)	(0.12)	(1.5)	(0.05)
Mart	13.2	71.7	447	453	2.97	22.9	0.37	0.82	0.05	0.74	14.8	0.34
Nimbukwaro	13.5	72.1	—	446	1.78	21.4	—	1.02	—	0.57	6.3	0.28
		(8.9)			(0.69)	(8.9)		(0.02)		(0.10)	(1.2)	(0.04)
Biartgu	24.8	79.2	—	323	1.71	14.0	—	0.73	—	0.63	3.9	0.30
		(2.1)				(0.45)						
Mean	17.0	74.0	420	412	2.11	19.6	0.30	0.90	0.07	0.65	8.2	0.30
SD	5.4	3.5	42	60	0.58	4.0	0.11	0.14	0.03	0.07	4.7	0.03
Grand mean[c]		76.0	370	377	2.07	17.7	0.32	0.94	0.07	0.74	6.2	0.28
SD		1.9	42	32	0.04	1.7	0.07	0.06	0.01	0.08	1.8	0.05
Takura[d]		74.8	347	399	2.28	16.6	1.45	1.59	0.07	0.76	9.8	0.39
		(2.9)			(0.08)	(4.0)	(0.36)	(0.27)	(0.01)	(0.12)	(5.7)	(0.03)

[a] Planted at Saramandi Research Station (Angoram District) in moderately heavy clay with evidence of sand, Numango near Balip Village (Maprik District) in heavy clay and at Mikau Village (South Wosera District) in sandy loam, harvested 20 August 1984. Numango and Mikau samples had no fertilizer. Some Saramandi samples had fertilizer added but there was no difference in results between those with fertilizer added (compound fertilizer 12% N, 6% P, 17% K) and those where no fertilizer was used (ACIAR/ANU Program 1985). Each result is the mean of 1-6 analyses on separate tubers of the same cultivar. Mean analyses for minerals, vitamins and organic acids given in Table 3.11.

[b] Yield (total fresh weight of tubers >250 g) t/ha; Table 7 of Quin (1984).

[c] Sum of a + b + c + d + e + f + g = 97.8.

[d] This cultivar of *D. esculenta* is of the family Asakua harvested October 1984 at Saramandi Research Station. Results are mean of four analyses on different tubers. It is grown without staking (Quin 1984). Tubers analysed were grown without fertilizer. Fertilizer had no effect on moisture or protein content (ACIAR/ANU Program 1985).

Table A.44. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for yam (*D. esculenta*) from Solomon Islands.

Amino acid	*GUP4 cv*	*NGP4 cv*	*NG4 cv*	*GUP5 cv*	*Mean*	*SD*
Alanine	319 (36)	252 (22)	290 (112)	406	—	—
Arginine	390 (25)	267 (31)	432 (25)	490	—	—
Aspartic acid	661 (15)	604 (69)	742 (129)	803	—	—
Cystine (Cys)	100 (16)	130 (20)	110 (10)	96	—	—
Glutamic acid	751 (100)	820 (105)	803 (112)	910	—	—
Glycine	257 (5)	221 (20)	231 (74)	303	—	—
Histidine	101 (25)	68 (21)	98 (54)	178	—	—
Isoleucine	294 (26)	126 (29)	178 (64)	276	—	—
Leucine	457 (61)	415 (95)	416 (91)	289	—	—
Lysine	259 (32)	130 (24)	159 (76)	302	—	—
Methionine (Met)	67 (0)	28 (14)	70 (34)	122	—	—
Phenylalanine (Phe)	309 (1)	188 (25)	237 (102)	260	—	—
Proline	370 (35)	210 (21)	241 (59)	304	—	—
Serine	282 (48)	234 (31)	257 (61)	268	—	—
Threonine	219 (9)	154 (33)	183 (74)	269	—	—
Tryptophan	111	—	—	107	—	—
Tyrosine (Tyr)	192 (16)	189 (28)	191 (95)	424	—	—
Valine	240 (18)	178 (53)	235 (91)	338	—	—
Amino Acid Scores						
Histidine	85	59	82	150	94	39
S-containing (Cys + Met)	107	101	115	140	116	17
Isoleucine	168	72	102	158	125	46
Leucine	111	100	101	70	96	18
Lysine	71	36	44	83	59	22
Aromatic (Phe + Tyr)	127	96	109	174	127	34
Threonine	103	72	86	126	97	23
Tryptophan	185	—	—	178	182	5
Valine	110	81	107	154	113	30
% Recovery of N	66 (14)	58 (3)	81 (4)	—	68	12

Table A.45. Yam (*D. nummularia*): popular cultivars from Western Samoa.[a]

		Dn 10 cv	*Dn 12 cv*	*Mean*[b]	*SD*
Moisture %	a	65.8 (1.7)	77.0 (3.0)	71.4	7.9
Energy (kJ/100 g)					
E_a		520	334	427	132
E_b		555	362	459	136
Protein %	b	2.25 (0.53)	1.51 (0.22)	1.88	0.52
Starch %	e	28.3 (2.0)	17.7 (2.9)	23.0	7.5
Sugar %	f	0.01 (0.01)	0.24 (0.12)	0.13	0.17
Dietary fibre %	g	0.59 (0.06)	2.06 (0.68)	1.33	1.04
Fat %	c	0.02 (0.01)	0.06 (0.02)	0.04	0.03
Ash %	d	1.14 (0.08)	0.69 (0.01)	0.92	0.32
Calcium (mg/100 g)		9.2 (2.7)	6.3 (1.4)	7.8	2.1
Iron (mg/100 g)		0.60 (0.08)	0.24 (0.01)	0.42	0.25

[a] Grown at University of South Pacific School of Agriculture, Alafua, in same plot, planted 20 September 1985, 1 × 1 m spacing staked, fertilised 11 November 1985 with 60 ml of 12-5-20 per plant harvested 1 August 1986, rainfall ~3000 mm/year. Processed immediately on arrival in Canberra; results are mean values from analysis of five tubers of each cultivar.

[b] Sum of a + b + c + d + e + f + g = 98.7.

Table A.46. Yam (*D. nummularia*): popular cultivars from Vanuatu.[a]

		7 cv	*14 cv*	*153 cv*	*211 cv*	*218 cv*	*Mean*[b]	*SD*
Moisture %	a	74.0 (2.0)	72.2 (0.9)	69.2 (4.7)	71.6 (0.6)	66.1 (2.0)	70.6	3.1
Energy (kJ/100 g)								
E_a		402	418	469	415	508	442	45
E_b		413	444	496	455	550	472	53
Protein %	b	1.65 (0.40)	2.40 (0.25)	2.16 (0.49)	2.57 (0.39)	2.19 (0.28)	2.19	0.35
Starch %	e	21.8 (1.5)	21.8 (2.0)	25.2 (1.6)	21.2 (0.5)	27.0 (1.3)	23.4	2.6
Sugar %	f	0.11 (0.05)	0.31 (0.06)	0.12 (0.10)	0.46 (0.04)	0.49 (0.16)	0.30	0.18
Dietary fibre %	g	1.80 (0.76)	3.20 (0.55)	1.60 (0.08)	2.98 (0.58)	2.13 (0.42)	2.34	0.71
Fat %	c	0.06 (0.03)	0.06 (0.01)	0.05 (0.04)	0.07 (0.01)	0.10 (0.03)	0.07	0.02
Ash %	d	0.92 (0.05)	0.92 (0.05)	0.95 (0.05)	0.91 (0.02)	1.13 (0.03)	0.97	0.09
Minerals (mg/100 g)								
Ca		3.09	4.06	5.64	5.60	7.0	5.08	1.5
P		27.9	41.7	43.3	45.0	—	39.5	7.8
Mg		14.1	23.2	18.3	24.7	—	20.1	4.9
Na		7.4	9.2	10.0	7.7	—	8.6	1.2
K		384	477	500	432	—	448	51
S		12.5	15.5	17.0	14.2	—	14.8	1.9
Fe		0.26	0.33	0.35	0.27	0.51	0.34	0.10
Cu		0.36	0.30	0.40	0.29	—	0.34	0.05
Zn		0.44	0.49	0.46	0.60	—	0.50	0.07
Mn		0.03	0.05	0.03	0.04	—	0.04	0.01
Al		0.26	0.17	0.54	0.19	—	0.29	0.17
B		0.06	0.05	0.07	0.04	—	0.05	0.01

[a] Samples obtained October 1986. Results are the mean of analyses on three tubers of each cultivar.
[b] Sum of a + b + c + d + e + f + g = 99.9.

Table A.47. Amino acid analyses (mg amino acid/g N sample) and amino acid scores for yam *D. nummularia* from Western Samoa.[a]

Amino acid	*Dn 10 cv tuber 3*	*Dn 12 cv tuber 1*	*Dn 12 cv tuber 3*	*Mean*	*SD*
Alanine	385	256	298	—	—
Arginine	671	473	472	—	—
Aspartic acid	1218	630	484	—	—
Cystine (Cys)	167	98	68	—	—
Glutamic acid	872	958	758	—	—
Glycine	321	211	249	—	—
Histidine	158	98	89	—	—
Isoleucine	295	202	164	—	—
Leucine	504	380	308	—	—
Lysine	318	217	166	—	—
Methionine (Met)	106	74	52	—	—
Phenylalanine (Phe)	292	310	132	—	—
Proline	428	223	167	—	—
Serine	331	284	343	—	—
Threonine	304	175	167	—	—
Tryptophan	124	46	45	—	—
Tyrosine (Tyr)	203	174	102	—	—
Valine	278	213	192	—	—
Amino Acid Scores					
Histidine	133	82	74	96	32
S-containing (Cys + Met)	175	110	77	121	50
Isoleucine	169	115	94	126	39
Leucine	122	92	75	96	24
Lysine	87	60	46	64	21
Aromatic (Phe + Tyr)	126	123	59	103	38
Threonine	143	82	78	101	36
Tryptophan	207	77	75	120	76
Valine	127	97	88	104	20
% recovery of N	95	67	61	74	18

[a] See Table A.45.

Table A.48. Yam (*D. bulbifera, D. pentaphylla, D. rotundata* and *D. trifida*): popular cultivars from Vanuatu.[a]

		D. bulbifera					*D. pentaphylla*				*D. rotundata*	*D. trifida*
		64 cv	*88 cv*	*251 cv*	*348 cv*	*Mean*	*22 cv*	*263 cv*	*351 cv*	*Mean*	*10 cv*	*29 cv*
Moisture %	a	83.0 (1.0)	77.6 (2.2)	84.0 (0.8)	82.2 (0.4)	81.7 (2.8)	84.4 (2.1)	80.3 (0.7)	82.7 (0.2)	82.5 (2.1)	65.7 (1.0)	80.7 (0.5)
Energy (kJ/100 g)												
E_a		231	318	174	225	237 (66)	226	314	258	265	542	272
E_b		256	350	239	270	279 (49)	232	303	262	266 (36)	557	296
Protein %	b	1.81 (0.22)	3.17 (0.34)	1.38 (0.09)	1.40 (0.40)	1.94 (0.84)	1.44 (0.50)	1.83 (0.04)	1.69 (0.08)	1.65 (0.20)	1.42 (0.03)	1.52 (0.42)
Starch %	e	11.6 (0.7)	15.3 (1.1)	8.6 (0.4)	11.3 (0.2)	11.7 (2.9)	11.7 (1.3)	16.6 (0.7)	13.4 (0.2)	13.9 (2.5)	30.2 (0.7)	14.2 (1.0)
Sugar %	f	0.08 (0.04)	0.14 (0.05)	0.21 (0.18)	0.36 (0.02)	0.20 (0.12)	0.11 (0.06)	0.10 (0.01)	0.14 (0.01)	0.12 (0.02)	0.32 (0.08)	0.23 (0.10)
Dietary fibre %	g	1.29 (0.09)	1.42 (0.09)	1.49 (0.08)	1.47 (0.14)	1.42 (0.09)	0.66 (0.14)	—	—	0.66 (0.14)	0.63 (0.10)	1.02 (0.16)
Fat %	c	0.04 (0.02)	0.04 (0.01)	0.04 (0.03)	0.07 (0.01)	0.05 (0.02)	0.02 (0.01)	0.04 (0.03)	0.02 (0.01)	0.03 (0.01)	0.09 (0.01)	0.04 (0.02)
Ash %	d	0.81 (0.05)	0.84 (0.07)	0.53 (0.07)	0.59 (0.07)	0.69 (0.16)	0.73 (0.07)	0.81 (0.01)	0.75 (0.03)	0.76 (0.04)	0.73 (0.01)	0.70 (0.08)
Minerals (mg/100 g)												
Ca		6.7	6.7	7.7	12.4	8.4 (2.8)	12.6	19.4	8.1	13.4 (5.7)	4.6 (0.04)	8.0 (3.1)
P		27.2	47.6	15.8	15.2	26.5 (15)	23.7	25.3	28.2	25.7 (2.3)	28.2 (0.6)	37.8 (2.3)
Mg		23.6	22.9	12.0	17.3	19.0 (5.4)	20.1	25.7	21.6	22.5 (2.9)	17.3 (0.8)	15.4 (0.7)
Na		2.92	3.69	2.51	1.73	2.71 (0.82)	4.15	8.23	5.89	6.09 (2.1)	4.74 (3.1)	2.86 (0.36)
K		452	447	232	253	346 (120)	362	383	377	374 (11)	361 (19)	350 (41)
S		10.6	15.0	5.6	4.9	9.0 (4.7)	13.0	11.5	15.8	13.4 (2.2)	12.4 (0.5)	8.2 (2.1)
Fe		0.51	0.66	0.43	0.65	0.56 (0.11)	0.32	0.65	0.39	0.44 (0.16)	0.60 (0.12)	0.54 (0.20)
Cu		0.25	0.23	0.22	0.14	0.21 (0.05)	0.24	0.21	0.29	0.25 (0.04)	0.12 (0.01)	0.13 (0.03)

Zn	0.28	0.45	0.26	0.23	0.31 (0.10)	0.32	0.34	0.41	0.36 (0.05)	0.30 (0.01)	0.35 (0.02)
Mn	0.15	0.14	0.06	0.17	0.13 (0.05)	0.04	0.06	0.05	0.05 (0.01)	0.03 (0.00)	0.03 (0.00)
Al	0.21	0.32	0.47	0.96	0.49 (0.33)	0.26	1.14	0.45	0.62 (0.46)	0.63 (0.46)	0.41 (0.19)
B	0.12	0.10	0.07	0.13	0.10 (0.03)	0.15	0.17	0.20	0.17 (0.03)	0.08 (0.01)	0.11 (0.01)
Sum of a + b + c + d + e + f + g	—	—	—	—	97.7	—	—	—	99.6	99.1	98.4

[a] Each result is the mean of three analyses on three tubers of each cultivar.

Table A.49. Composition of popular cassava cultivars from Solomon Islands.[a]

Cultivar	Total yield (t/ha)	Moisture %	Energy (kJ/100 g)		Protein %	Starch %	Sugar %	Dietary fibre %	Fat %	Ash %	Calcium (mg/100 g)	Iron (mg/100 g)	Trypsin inhibitor (TIU/g)	Cyanide (mg/100 g)[c]	
			E_a	E_b										Free	Total
		a			b	e	f	g	c	d					
WSH 9	34.2	66.4	493	545	0.67	27.6	0.71	1.57	0.09	0.80	29.3	0.37	0[b]	5.46	5.52
		(1.1)			(0.26)	(1.0)	(0.12)	(0.12)	(0.02)	(0.03)	(1.7)	(0.06)		(3.12)	(3.09)
Tikopia	27.9	65.4	506	562	0.84	28.3	0.62	1.44	0.10	0.72	24.4	0.33	0	5.37	5.49
		(1.0)			(0.13)	(0.7)	(0.28)	(0.09)	(0.03)	(0.02)	(2.6)	(0.01)		(1.76)	(1.65)
Malaita red	35.4	60.3	600	651	0.79	33.8	0.67	1.24	0.13	0.76	11.6	0.31	0	2.66	2.64
		(1.8)			(0.02)	(2.3)	(0.22)	(0.04)	(0.02)	(0.02)	(0.3)	(0.04)		(0.74)	(0.74)
WSH 1	16.3	62.2	561	618	0.40	31.7	0.87	1.48	0.13	0.68	16.2	0.37	0	2.37	2.47
		(2.1)			(0.01)	(2.1)	(0.09)	(0.07)	(0.01)	(0.04)	(3.2)	(0.04)		(0.33)	(0.42)
Betikama	23.8	72.9	412	432	0.64	22.3	1.18	1.47	0.16	0.50	18.5	0.26	0	3.37	3.48
		(2.2)			(0.06)	(3.0)	(0.10)	(0.11)	(0.04)	(0.03)	(3.6)	(0.02)		(0.47)	(0.43)
Maliae 2	13.9	69.4	455	493	0.61	24.0	2.08	1.56	0.15	0.67	15.8	0.25	0	4.45	4.51
		(4.6)			(0.34)	(4.8)	(0.18)	(0.13)	(0.06)	(0.11)	(2.4)	(0.03)		(0.51)	(0.62)
Curry Gizo	18.5	66.2	513	548	0.44	28.1	1.59	1.50	0.16	0.66	24.6	0.15	0	2.62	2.70
		(1.1)			(0.07)	(0.6)	(0.22)	(0.31)	(0.01)	(0.03)	(1.5)	(0.02)		(0.10)	(0.15)
WSH 5	22.6	63.2	553	601	0.84	30.5	1.15	1.30	0.13	0.65	14.1	0.27	0	3.73	3.96
		(2.3)			(0.18)	(2.0)	(0.18)	(0.10)	(0.02)	(0.06)	(1.5)	(0.03)		(1.40)	(1.34)
WSH 2	27.2	69.7	470	488	0.57	25.7	1.39	1.31	0.12	0.66	13.1	0.20	0	2.07	2.19
		(4.0)			(0.13)	(3.3)	(0.83)	(0.11)	(0.03)	(0.05)	(1.5)	(0.02)		(0.37)	(0.39)
Mean[d]	24.4	66.2	507	549	0.64	28.0	1.14	1.43	0.13	0.69	18.6	0.28	—	3.57	3.66
SD	7.5	4.0	60	69	0.16	3.8	0.49	0.12	0.02	0.06	6.1	0.07	—	1.28	1.28

[a] Grown at Dodo Creek, sandy soil, planted 24 November 1984, harvested 8 September 1985. Fertiliser applied as split dressing at 1 and 4 months. Ammonium sulfate 300 kg/ha, potassium chloride 300 kg/ha. Results are mean of analyses on three tubers of each cultivar. Other minerals, organic acids and vitamin analyses given in Table 3.14.

[b] Estimated to be <0.1 TIU/g.

[c] Cassava cut tissue stored in deep freeze for 6 months before cyanide analysis.

[d] Sum of a + b + c + d + e + f + g = 98.2.

Table A.50. Composition of tubers of popular cassava cultivars from Fiji.[a]

		Navolau cv	Beqa cv	Vulatolu cv	Sokobale cv	New Guinea cv	Mean[b]	SD
Yield (t/ha)		31.6	29.3	24.2	20.0	30.0	—	—
Moisture %	a	64.7	58.3	64.7	60.2	60.0	61.6	2.9
		(5.6)	(5.1)	(2.4)	(1.9)	(2.5)		
Energy (kJ/100 g)								
E_a		519	644	516	588	591	571	55
E_b		575	686	575	653	656	629	51
Protein %	b	0.56	0.67	0.46	0.56	0.45	0.54	0.10
		(0.04)	(0.13)	(0.03)	(0.06)	(0.08)		
Starch %	e	28.4	36.1	28.3	33.3	33.4	31.9	3.5
		(6.0)	(4.6)	(2.7)	(1.9)	(4.3)		
Sugar %	f	1.25	0.90	1.42	0.47	0.96	1.00	0.36
		(0.59)	(0.17)	(0.40)	(0.11)	(0.10)		
Dietary fibre %	g	1.76	1.28	1.33	1.36	1.51	1.45	0.19
		(0.15)	(0.30)	(0.19)	(0.11)	(0.25)		
Fat %	c	0.24	0.22	0.21	0.23	0.10	0.20	0.06
		(0.03)	(0.02)	(0.01)	(0.09)	(0.06)		
Ash %	d	0.94	0.99	1.00	0.95	0.91	0.96	0.04
		(0.08)	(0.08)	(0.08)	(0.10)	(0.04)		
Calcium (mg/100 g)		19.0	18.6	21.2	20.0	15.4	18.8	2.2
		(2.2)	(3.5)	(3.8)	(5.0)	(0.9)		
Iron (mg/100 g)		0.22	0.20	0.24	0.25	0.13	0.21	0.05
		(0.04)	(0.03)	(0.04)	(0.04)	(0.04)		
Cyanide (mg/100 g)[c]								
Free		1.00	1.04	0.90	0.30	0.60	0.77	0.31
		(0.60)	(0.24)	(0.70)	(0.12)	(0.42)		
Total		2.41	3.40	3.15	2.69	2.36	2.80	0.46
		(0.65)	(0.96)	(0.92)	(0.85)	(2.20)		

[a] Planted 23 April 1985, harvested 26 June 1986 at Koronivia Research Station. Fertilizer was urea (50 kg/ha) applied 8 weeks after planting. Total rainfall over life of crop 4400 mm. Results are mean of analyses on five tubers of each cultivar.

[b] Sum of a + b + c + d + e + f + g = 97.7.

[c] These cyanide results were obtained on fresh samples. Samples were also stored at −20 °C for 5 months and gave total cyanides for Navolau, Beqa, Vulatolu and Sokobale of 1.17, 2.20, 3.10 and 2.90 respectively.

Table A.51. Composition of cassava cultivars from PNG.[a]

		White	Yellow	L4	L12	L19	L23	Mean[b]	SD
Moisture %	a	61.1	59.3	63.5	62.0	61.7	56.8	60.7	2.4
		(4.2)	(3.2)	(7.7)	(2.9)	(7.5)	(1.9)		
Energy (kJ/100 g)									
E_a		573	619	532	552	556	636	578	40
E_b		637	668	595	621	627	712	643	41
Protein %[d]	b	0.37	0.54	0.34	0.39	0.45	0.32	0.40	0.08
		(0.05)	(0.12)	(0.07)	(0.07)	(0.12)	(0.06)		
Starch %	e	32.9	35.6	30.4	31.5	32.0	36.5	33.2	2.5
		(3.5)	(2.7)	(8.0)	(3.0)	(6.0)	(1.1)		
Sugar %	f	0.37	0.18	0.33	0.39	0.18	0.58	0.34	0.15
		(0.18)	(0.05)	(0.10)	(0.18)	(0.10)	(0.19)		
Dietary fibre %	g	1.50	1.41	1.47	1.56	1.62	1.83	1.57	0.15
		(0.14)	(0.34)	(0.23)	(0.23)	(0.24)	(0.25)		
Fat %	c	0.13	0.12	0.20	0.20	0.14	0.17	0.16	0.04
		(0.03)	(0.02)	(0.02)	(0.02)	(0.05)	(0.02)		
Ash %	d	0.84	0.91	0.81	0.84	0.88	0.89	0.86	0.04
		(0.06)	(0.04)	(0.08)	(0.05)	(0.10)	(0.05)		
Calcium (mg/100 g)		24.9	21.7	25.5	23.0	19.6	17.9	22.1	3.0
		(2.8)	(1.9)	(3.9)	(5.6)	(0.7)	(2.4)		
Iron (mg/100 g)		0.21	0.18	0.17	0.23	0.16	0.22	0.20	0.03
		(0.04)	(0.03)	(0.05)	(0.03)	(0.03)	(0.02)		
Cyanide (mg/100 g)[c]									
Free		2.06	2.07	3.37	1.31	1.23	6.21	2.69	1.88
		(0.16)	(0.67)	(1.25)	(0.63)	(0.41)	(0.86)		
Total		2.20	2.10	3.48	1.43	1.33	6.29	2.78	1.87
		(0.18)	(0.63)	(1.39)	(0.69)	(0.53)	(0.88)		

[a] Planted January 1985 at Laloki Research Station, harvested January 1986, no fertilizer or irrigation used. Total rainfall over life of crop about 1200 mm. Yellow and white are the most popular varieties around Port Moresby. The other four cultivars were originally from Lowlands Agricultural Experimental Station, Keravat, New Britain. Results are mean of separate analyses on five tubers of each cultivar. Other mineral and organic acid analyses given in Table 3.15.

[b] Sum of a + b + c + d + e + f + g = 97.2.

[c] Cassava cut tissue stored in deep freeze at -20°C for 4 months before analysis.

[d] These low protein results were double-checked, total of 60 Kjeldahl nitrogen analyses.

Table A.52. Amino acid analyses (mg amino acid/g N) and amino acid scores of cassava tubers from Solomon Islands and PNG.

	Solomon Islands			PNG			
Amino acid	Malaita Red cv	Curry Gizo cv	Tikopia cv	Yellow cv	White cv	L12 cv	Mean
Alanine	386	288	265	443	404	352	—
Arginine	297	129	158	122	205	140	—
Aspartic acid	494	424	392	976	762	520	—
Cystine	108	81	86	226	236	144	—
Glutamic acid	636	743	529	1187	898	632	—
Glycine	311	222	226	236	330	232	—
Histidine	116	106	83	102	92	76	—
Isoleucine	310	280	261	120	224	168	—
Leucine	450	295	291	376	410	279	—
Lysine	354	357	275	372	357	264	—
Methionine	45	194	95	130	132	133	—
Phenylalanine (Phe)	275	199	150	141	249	182	—
Proline	162	142	133	179	185	187	—
Serine	182	125	116	385	284	192	—
Threonine	200	156	145	381	326	196	—
Tryptophan	—	—	—	56	49	—	—
Tyrosine (Tyr)	275	258	213	115	250	182	—
Valine	323	245	246	161	280	315	—
Amino Acid Scores							
Histidine	98	89	69	86	77	62	80 (13)
S-containing (Cys + Met)	98	176	116	228	236	177	172 (56)
Isoleucine	177	160	149	69	128	96	130 (41)
Leucine	109	71	71	91	99	68	85 (17)
Lysine	97	98	76	103	99	72	91 (13)
Aromatic (Phe + Tyr)	140	116	92	65	127	92	105 (27)
Threonine	94	73	68	179	153	92	110 (45)
Tryptophan	—	—	—	93	82	—	88 (8)
Valine	147	112	112	74	128	144	120 (27)
% Recovery of N	67	63	50	86	77	53	66 (14)