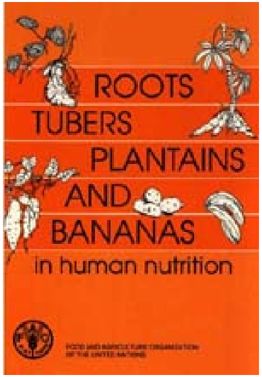

Roots, tubers, plantains and bananas in human nutrition

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 1990

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Contents

[Bibliography](#)

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Acknowledgments

Contents - Next

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Preface

During the last 15 years the difficulties faced by many developing countries in satisfying their population's requirements with domestic food production have increased. Even with sustained efforts, it has not always been possible to meet the growing food demand by raising the domestic production of cereals. As a result widespread food shortages, hunger and malnutrition have persisted, particularly among the low-income groups in developing countries.

In order to improve the situation, the Member Governments of the Food and Agriculture Organization of the United Nations (FAO) at the 8th Session of the Committee on Agriculture (COAG) in 1985 recommended the adoption of measures to broaden the food base through the promotion of other local food crops of nutritional importance. More recently, at its 9th session, COAG further requested Member Governments to give high priority to production and consumption of roots, tubers, plantains and bananas in view of their important role in improving food security.

Although these crops have been for centuries the traditional staples in many developing countries they have until recently been relatively neglected by most national research institutes, extension services and by food supply planners. While part of this neglect can be attributed to difficulties in marketing and processing these perishable food crops, they have also suffered from a negative image as "poor people's food ". Starchy roots and tubers, such as cassava, have been traditionally associated poverty and accused of being a factor contributing to the development of kwashiorkor, a form of severe protein energy malnutrition. Since most of these food crops are consumed locally or sold in nearby small markets their actual contribution to the energy intake of rural populations producing them is not fully accounted for. Their consumption in urban areas is far from negligible, especially in Africa and in Asia. This is why it is time to bring out the positive attributes of these important foods and the increased contribution they can make to the nutritional welfare and food security of developing countries.

In this book the value of roots, tubers, plantains and bananas in human nutrition and their importance in human diet is reviewed. The purpose of this book is to promote their production and utilization as valuable components of a well-balanced diet, and to alleviate hunger and seasonal food shortages.

The book is intended for nutritionists, agriculturists, dieticians, community development workers, school teachers and economists. It is hoped that officials responsible for planning food supply, production and food imports and exports will find the facts presented useful for their work. Educationists will also find valuable information that will help them lo promote changes in the food habits of population groups, particularly those who suffer chronically from energy deficiency and food insecurity.

P. Lunven
Director
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1. Introduction

Roots and tubers belong to the class of foods that basically provide energy in the human diet in the form of carbohydrates. The terms refer to any growing plant that stores edible material in subterranean root, corm or tuber.

The development of root crops in the tropics was accelerated by the introduction of gari-processing technology into West Africa and by the promotion of cassava as a famine reserve by several colonial governments, such as the Dutch in Java and the British in West Africa and India. By 1880 the tapioca trade was well established in Malaya and by the turn of the twentieth century the production and trade of cassava products, especially starch, had been established by the Dutch in Java and by the French in Madagascar.

A further reason for the spread was the fact that during tribal warfare and invasions, the invader could not destroy or remove the food reserve, which could be kept conveniently under the ground, thus giving added food security to the population.

Historically, very little attention has been paid to root crops by policy-makers and researchers as most of their efforts have been concentrated on cash crops or the more familiar grains. Root crops were regarded as food mainly for the poor, and have played a very minor role in international trade. This misconception has lingered for so long because of the lack of appreciation of the number of people who depend on these root crops, and the number of lives that have been saved during famine or disasters by root crops.

It was cassava that saved the Rwanda-Burundi kingdoms in 1943 when potato blight destroyed all their production, and cassava also fed the Biafrans during the Biafran war in Nigeria in 1966-69.

As far back as 1844 Rev. John Graham has this to say about the potato:
"Oh! There's not in the wide world a race that can beat us,
From Canada's cold hills to sultry Japan,
While we fatten and feast on the smiling potatoes
Of Erin's green valleys so friendly to man."

There is an old saying of the Palananans of Micronesia where taro is the basis of the staple food that:
"the taro swamp is the mother of life" (Kahn, 1985).

The fact that these root crops are mainly starchy has led to the disparagement of their protein content, which is low compared to cereals. However, considering the quantities of root crops consumed a day, their protein contribution is often significant. In addition, root crops contain an appreciable amount of vitamins and minerals and may have a competitive production advantage in terms of energy yield per hectare over cereals produced in ecologically difficult conditions.

During the years 1980-87, the average rate of growth in food production (2.6 percent) in many countries of developing market economies, particularly Africa, has been either falling behind or barely keeping pace with the average annual rate of growth in population (about 3 percent), owing to land shortages and lack of foreign exchange to purchase agricultural inputs such as fertilizers, insecticides and m achinery. Droughts, floods and other natural and induced calamities have contributed substantially to reduced food supplies. These fooddeficit countries are now making substantial efforts to improve this situation, but their efforts are directed mainly toward improving production of staple cereals and increasing the importation of cereals by cash purchases or as food aid, thereby widening further the gap between local food production and food requirements.

In their present state under subsistence farming, the yield of many root crops is very low, but their genetic potential for producing increased yields is high and has not yet been fully exploited. In addition some root crops are highly adaptable, producing reasonable yields from marginal lands with highly erratic rainfalls. Crops such as cassava can serve as a valuable asset for household food security for subsistence populations in times of drought and under other unfavourable ecological conditions.

The purpose of this book is to review the value of roots and tubers in the human diet and to assess their contribution to the nutritional welfare and food security of people living in less developed countries. It is hoped that it will also help propagate knowledge about these crops and stimulate research for their genetic improvement with a view to increasing their production and utilization.

In its Food and Nutrition Papers and Series, the Food and Agriculture Organization of the United Nations (FAO) has already published books on five important food sources, namely Rice and rice diets, Maize and maize diets, Milk and milk products in human nutrition, Wheat in human nutrition and Legumes in human nutrition. The present study has been conceived on a similar pattern. It will summarize current knowledge about production, consumption, nutritive value, processing and cooking of roots and tubers and their contribution to hum an diets. The study includes all important root and tuber crops: cassava, yam, sweet potato, potato and aroids as well as two other starchy staples, banana and plantain. Although much of the research and development work on potato is done in temperate zones, the potato is included in the book because of its great potential for expansion into the tropics. Plantain and banana are also important starchy staples in many tropical countries.

In 1988 FAO published a study entitled Root and tuber crops, plantains and bananas in developing countries: challenges and opportunities, which provides a comprehensive review of the global production and consumption of these crops. Additional FAO studies in this field focus on the utilization and processing of roots, tubers, plantains and bananas. The present study provides a more detailed analysis of the role of these crops in human nutrition and is an essential supplement to the information provided in the earlier publications.

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2. Origins and distribution

The suggested origins of root and tuber crops are illustrated in Table 2.1. These crops were dispersed by the Portuguese during their voyages for slaves, by both the Portuguese and Spanish in their missionary journeys, and by Arab traders. The genus Dioscorea (a variety of yam) has a wider diversity of origin with different species adapted to different ecosystems. D. trifida is indigenous to tropical America; D. rotundata, D. cayenensis, D. bulbifera and D. dumetorum are native to West Africa; D. alata, D. esculenta and D. opposita are indigenous to South Asia. D.

opposita and D. japonica have their centre of origin in China.

Yams are the only root crops in which the Asian and African species developed independently of each other. Exchange of species was due to the influence of Portuguese explorers. They learned of the value of D. alata from the Indian and Malayan seafarers who used it on their ships on long voyages because it stored well and had antiscorbutic properties. The Portuguese soon adopted it and introduced it into Elmina and Sao Tome in West Africa. Subsequently, through the Atlantic slave trade, the Portuguese carried the African species D. rotundata and D. cayenensis and the Asian species D. alata to the Caribbean where they became important staple foods (Coursey, 1976). According to Coursey (1967), D. alata seems to have arisen from the wild relatives, D. hamiltoni and D. persimilis in the north and central pans of the southeast Asian peninsula, probably Burma or Assam. So also D. esculenta while D. hispida, D. pentaphylla and D. bulbifera origina ted from an IndoMalayan centre. D. rotundata is of African origin, where it is known as "water yam", indicating that it was brought across the water or sea. D. rotundata is the most important African yam, especially in the forest zone, and is probably a hybrid of the other African yam, D. cayenensis, which is a savannah species. In West Africa it is grown in the roots and tubers belt, which extends 15N and 15S of the equator (Coursey, 1976; Okigbo, 1978; Nweke, 1981).

TABLE 2.1 - Origins of tropical root crops

Root crop	Common name	Suggested origin
American species		
Ipomoea batatas	sweet potato	Tropical North America (Mexico, Central

		America and Caribbean)
Manihot esculenta	cassava, cocoyam	Tropical Central America (from Caribbean to Northeast Brazil)
Xanthosoma sagittifolium	new cocoyam, taro	Tropical Central America (from Caribbean to North Brazil)
Solanum tuberosum	potato	Andean South America (Colombia, Bolivia and Peru)
Dioscorea trifida	sweet yam	Tropical Central America (Guyana, Surinam)
African species		
Dioscorea rotundata	yam	Tropical West Africa
Dioscorea cayenensis	wild yam	Tropical West Africa
Dioscorea dumetorum	"	Tropical West Africa
Dioscorea bulbifera	"	Tropical West Africa
Asian species		
Dioscorea alata	yam	South Asia
Dioscorea esculenta	"	South Asia
Dioscorea opposita	"	South Asia
Colocasia esculenta	old cocoyam or taro	Southeast Asia

Musa acuminate	banana/plantain	Southeast Asia

Source: Adapted from Purseglove (1968,1972).

Little is known about the origin of new world yams. They were of secondary importance in the pre-Colombian era. D. trifida, an Amerindian domesticate, appears to have originated on the borders of Brazil and Guyana, followed by a dispersion through the Caribbean (Ayensu and Coursey, 1972). Yams were taken to the Americas through precolonial Portuguese and Spanish expansion that began around 500 years ago. Historical records of D. alata in West Africa and of African yams in the Americas date back to the sixteenth century (Coursey, 1967).

Sweet potato, which originated in the Yucatan peninsula in Latin America, seems to be the most widely dispersed root crop. It is adaptable and can grow under many different ecological conditions. It has a shorter growth period than most other root crops (three to five months) and shows no marked seasonality: under suitable climatic conditions it can be grown all the year round. Adverse weather conditions rarely cause a complete crop loss. Hence sweet potatoes are planted as an "insurance crop", combined in mixed cropping with grains like rice in Southeast Asia, and with other root crops like cocoyam and yam in Oceania. It is a popular plant in the Philippines and in Japan because of its prostrate habit, which makes it resistant to damage by high winds such as hurricanes and typhoons (Wilson, 1977). Sweet potatoes have been cultivated since about 3 000 B.C. and were an important food for the Mayans in Central America and the Peruvians in the Andes. From ethno-historical records of Colombia, the reports of Spanish explorers and missionaries in Mexico and Peru, and of the Portuguese in Brazil, it is clear that sweet potato was common throughout the American tropics before 1492. The plant was further

dispersed by Iberian and Portuguese explorers to the Pacific area in the sixteenth century. The Portuguese explorers subsequently transferred West Indian clones, grown in the western Mediterranean area, to Africa, India and the East Indies. Spanish traders also took sweet potatoes from Mexico to Manila. Later the sweet potato reached New Guinea and the eastern Pacific Islands and extended into China and Japan. It is now grown extensively in a wide range of environments between latitude 40N and 40S and from sea level up to an altitude of 2 300 metres.

The distribution of potato is also extensive. It originated in the high Andes of South America where it was adapted to the cold climate and short days prevailing in those latitudes. Wild cultivars are still found on elevated regions extending from the southwestern part of the United States of America to the southern part of South America, and more especially at high altitudes in Bolivia and Peru and in the coastal regions and nearby islands of southern Chile (Simmonds, 1976). When the original potato was first introduced to Europe it remained a botanical curiosity for more than a century and it did not flourish until a variety adapted to the longer day was evolved.

Spanish sailors introduced the potato to Spain as early as 1573. It was probably introduced into England by English seamen from captured Spanish ships around 1590. From Spain, potatoes spread throughout continental Europe; from England, they were dispersed throughout Great Britain to parts of northern Europe. By 1600, potatoes were sent from Spain to Italy and from there to Germany and in the same year they reached France.

Potatoes reached most other parts of the world through European colonial activities. North America received potatoes from England in 1621, British missionaries took potatoes to Asia in the

seventeenth century and Belgium missionaries carried them to the Congo in the nineteenth century. The potato was brought to India in the sixteenth century by Portuguese traders and within about 200 years it had spread all over India. It was taken to Bhutan, Nepal and Sikkin from India. In Africa, introduction of potatoes followed colonization. Possibly, its antiscorbutic properties persuaded seafarers to stock it in their ship's store and to encourage people to grow it wherever they visited.

Like sweet potato, potato also exhibits a growing period of about four months, shorter than many other root crops. The indigenous South American cultivars will develop tubers at longer day lengths than other root crops and numerous cultivars will even tolerate the extreme day length of 24 hours of the polar summer (Kay, 1973). So the spread was very easy.

A typical example of a root crop that can tolerate drought and poor husbandry is cassava. Cassava originated in tropical America but the precise area of its origin is not known. The two probable areas suggested are the Mexican and Central American area or northern South America. It was first introduced into the Congo basin as early as 1558 by the Portuguese. It then spread rapidly through Angola, Zaire, Congo and Gabon and later to West Africa. There was a separate introduction to the east coast of Africa and to Madagascar in the eighteenth century by Portuguese and Arab traders, after which it rapidly became a dietary staple throughout many lowland tropical areas (Jones, 1959). The cultivation of cassava in Africa increased during the nineteenth and twentieth centuries as a result of encouragement by administrative authorities, who recognized its value as a famine relief crop. According to Kahn (1985), after the First World War, the farmers of RuandaUrundi, now the independent nations of Rwanda and Burundi, at first refused to take advice from the Belgians to plant cassava, because they had enough potatoes. But

in 1924 the Belgians issued a strict order to grow cassava and recruited 60 000 porters to carry 5 000 tonnes of cassava stakes around the region for planting, so the farmers finally accepted.

Cassava was taken to India by the Portuguese in the seventeenth century. In about 1850, it was transported directly from Brazil to Java, Singapore and Malaya. Cassava was introduced to the South Pacific territories during the first half of the nineteenth century by missionaries and travellers but its importance varies from island to island. At present, cassava is grown throughout tropical and subtropical areas approximating 30N and 30S of the equator and up to an altitude of 1 500 metres.

The spread of root crops was facilitated by their ability to thrive under varied tropical conditions. Their level of water tolerance varies considerably, ranging from the waterlogged conditions required for taro to the drought tolerance and minimal water supplies needed for cassava once it has been established (Wilson, 1977). It was the requirement of flooded conditions for taro, Colocasia esculenta, that convinced anthropologists that these yams were the first irrigated crops, and that the ancient "rice" terraces of Asia were originally constructed for them (Plucknett et al., 1970). Tannia (Xanthosoma sagittifolium) on the other hand cannot tolerate being waterlogged (Onwueme, 1978).

Xanthosoma, or new cocoyam, had its origin in South America and the Caribbean. The Spanish and Portuguese introduced it to Europe and were also responsible for spreading it to Asia. It moved from the Caribbean in the late nineteenth century, first to Sierra Leone and then to Ghana. In West Africa, Xanthosoma is more important than Colocasia, being popular for its corm, cormels, leaves and young stems. Although Xanthosoma is relatively new to the Pacific region, it has

spread rapidly and widely, becoming quite an important crop in many of the islands. It is also widely cultivated in Puerto Rico, the Dominican Republic and Cuba and is important along the coastal mountains of South America, in the Amazon basin and in Central America.

Colocasia originated in India and Southeast Asia. About 2 000 years ago it spread to Egypt and thence to Europe (Plucknett et al., 1970). Subsequently it was taken from Spain to tropical America and then to West Africa. It was used in feeding slaves and was transferred to the West Indies with the slave trade (Coursey, 1968). In order to distinguish it from the newer species, Xanthosoma, Colocasia was referred to as "old yam" in West Africa whereas Xanthosoma is called "new yam". Colocasia is a staple food in many islands of the South Pacific, such as Tonga and Western Samoa, and in Papua New Guinea. Colocasia and Xanthosoma will tolerate shade conditions and so they are often planted under permanent plantations like banana, coconut, citrus, oil palm and especially cocoa. Therefore they are sometimes collectively referred to as cocoyams.

The banana is believed to have originated in Southeast Asia, having been cultivated in South India around 500 BC. From here it was distributed to Malaya through Madagascar and linen moved eastward across the Pacific to Japan and Samoa in the mid-Pacific at about AD 1000. It was probably introduced to East Africa around AD 500 and had become well established in West Africa by AD 1400. It finally arrived in the Caribbean and Latin America soon after AD 1500 (Simmonds, 1962; 1966; 1976). By the end of the eleventh century, banana had spread widely throughout the tropics. In South America it was found as far south as Bolivia and was cultivated in most of Brazil. In Africa banana growing extended from the Sahara to Tanzania in the east and from Cte d'Ivoire through the Congo to Zaire in the west and central areas.

TABLE 2.2 - Minor root crops of local Importance

Local names	Root crop species	Suggested origin	Other names
Chayote	Sechium ecu/e	Mexico	Chinchayote, Guisquil (Spanish)
Jicama	Pachyrhyzus	Mexico	
Yam be an	Pachyrhyzus and Sphenoslylis stenocarpa		
Arrow root	Maranta arundinacea	Polynesia	Pana, Panapen
Arracachia	Arracacia xanthorrhiza		
Oca	Oxalis tuberosa		
Queensland arrowroot	Cana edulis		
Topee Tambo	Calathea allouia		
Ulluco	Ullucus ruberosus	Mellocco, oca-quira	
Yacon	Polymnia sonchifolia		

Apart from the major root crops discussed in this book, other root crops exist in different parts of the world, mainly in the Andean region, and are of local importance. Some of these are shown in

Table 2.2.

Contents - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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3. Production and consumption

Contents - Previous - Next

Production

According to a recent FAO estimate, virtually every country in the world grows some species of root crop. Most of the root crops considered in this study require tropical conditions and are restricted to Africa, Asia and Latin America. Only potatoes and some varieties of sweet potato are grown in large quantities in the temperate zone. These root crops are often the main dietary staple for low-income consumers. They are grown by farmers as subsistence crops on small plots of land ranging from two to 20 hectares depending on the region.

It has been estimated that about 82 percent of Paraguayan farmers grow cassava as a subsistence crop on small holdings, and whenever they move on to virgin land they first plant cassava. In Latin

America, 75 percent of the cassava farms are about 20 hectares or less, whereas in Java and Kerala the holding is about two hectares. In Thailand most producers have less than one hectare devoted to cassava. In 1982/83 the cultivation and harvesting of some 19 million tonnes of cassava in Thailand was carried out entirely by approximately 1.2 million smallholders who obtained yields of between 13 and 15 tonnes per hectare (FAO, 1984). Most of this production was processed, with 85 percent transformed into chips and pellets for animal feed and 15 percent used for starch production. Very little was used directly for human consumption.

In Africa these root crops are usually subsistence crops grown mainly as food, so the farmer keeps sufficient to feed his family and sells only the surplus. However, there is now a growing commercial market for them. Cassava is commercially processed into gari, a staple food in parts of Nigeria, and into kokonte in Ghana. In Brazil about 70 percent of the cassava harvest is marketed (Lynam and Pachico, 1982).

In subsistence production of cassava, yields are often low as a result of poor cultivation practices. Cassava is often grown on marginal land and as it grows relatively well on poor soils, with limited inputs, it is often planted as the last crop in a shifting cultivation system. On average, weeds reduce cassava yield by 59 percent. On newly cleared land no positive yield response is observed to either nitrogen or potash fertilizers. On poor land there may be some response to nitrogen, but fertilizer is not extensively applied. Even in Java in Indonesia, where land use is very intensive and the cost of fertilizer is heavily subsidized, only 8.1 kg of fertilizer/ha was used for cassava compared to 178.9 kg/ha average for all the other crops. In Brazil only about 9 percent of the cassava area is fertilized.

Most research to improve root crop production has been devoted to potato in temperate countries and in the tropics, especially at the International Centre for Potato Research (CIP) in Peru, and so it is not surprising that potato yields are much higher than those of the other root crops. In some parts of Latin America, however, it is still grown by subsistence farmers on a small scale, as part of a complex multiple-cropping system, on one to two hectare plots with low yields. In temperate zones and in cool highland areas, where it is usually grown under irrigation conditions and as a sole crop, yields are often very high. It is produced only in limited quantities in the tropics, cassava and sweet potatoes being the major crops there.

In 1982, the CIP estimated that there has been an overall increase in the total production of root crops in developing countries during the years from 1961 to 1979. However, when considered individually and regionally, production of crops like cassava has gone up, sweet potatoes have remained stagnant, while production of potatoes has decreased in industrialized countries, but increased in developing countries. Per caput production of root crops had fallen during this period in most developing countries. In sub-Saharan Africa, output of root crops, except sweet potato, failed to keep pace with population growth. In Latin America and the Caribbean, since 1970, production trends of starchy staples as a group have been negative (FAO, 1988a). Various reasons have been adduced for the decrease in production, including infestation by insects, parasites and diseases, bad weather and marketing problems.

That part of the root and tuber crop harvest which is produced by subsistence farmers for their own consumption does not enter the commercial marketing channels. It is thus difficult to obtain accurate data on total production of these crops. Today, FAO's statistics are the best available guide to global production of these crops.

Tables 3.1 and 3.2 provide production, acreage and yield figures for roots and tubers in various regions of the world. Among the five root crops listed, potatoes occupy a land area of about 20 million hectares or 44.3 percent of the total area of 46 million hectares devoted to world production of root crops. The potato is increasingly important in developing countries and is a good source of nutrients in the diet. Its protein: calorie ratio is as high as that of wheat (Table 4.10) and its productivity in terms of energy and protein per hectare per day is greater than that of most other staple food crops (Table 4.1).

Potato has the highest percentage of world production, accounting for 52.9 percent of the total in 1984, followed by cassava covering 14 million hectares (21.9 percent) and accounting for 30.9 percent of total production; then sweet potatoes covering about eight million hectares (16.9 percent) and accounting for 19.9 percent of total production. Yams cover about 3 million hectares (5.5 percent) with 4.3 percent of total production and the least important, taro, occupies I million hectares (2.5 percent) with 1.0 percent of total production.

Table 3.1 shows that potato is growing over a wide geographical spread in the countries producing this root crop, but the leading producers are all in temperate-zone areas (Table 3.3). Of the total of 130 potato-producing countries, 95 are developing countries and in 1978-81 they were able to produce less than 10 percent of the world production. However, by 1985 developing countries accounted for about one-third of world production, with China producing 60 percent of this contribution. The increase has been particularly significant in the Near East where production had gone up by 130 percent, in the Far East by 180 percent and in Africa by 120 percent. Potato is also a potentially high-yielding crop. The present average yield is only about 10 t/ha in developing countries but yields as high as 72 t/ha have been recorded on experimental research plots in the

Netherlands and this could be further increased by the use of improved varieties under conditions of good husbandry (Doku, 1984). At present the normal recorded yield for the United States of America is about 27.3 t/ha.

TABLE 3.1 - World area, production and yield of root crops in 1984

TABLE 3.2 - World area and production of root crops in 1984 (in percentages)

TABLE 3.3 - Leading root crop producers in 1984 (percentage of total)

In spite of the low production, potato has become an acceptable foodstuff in a number of developing countries, including China, Bolivia, Colombia, Ecuador, India, Guatemala, Kenya and Rwanda (see Table 3.4). After China, India is the leading producer, accounting for 3.6 percent of world production, followed by Turkey (1.1 percent), Brazil and Colombia (0.8 percent). Together these four countries account for over 50 percent of the production in developing countries but only 7 percent of the world production.

Present research projects at CIP include breeding varieties to tolerate tropical temperatures at altitudes down to 1 000 ft (300 m) or even lower. Great progress has recently been made in the field of tissue culture and genetics and it may not be long before the potato also becomes a common tropical root crop. This will materially assist the provision of additional food for the ever increasing population in this part of the globe. At present potatoes provide only a small percentage of dietary calories in most developing countries, as indicated in Table 3.4. Cassava and sweet potatoes are more important root crops providing a range from 57.9 percent of the calories

in Zaire to 35.2 percent in Angola.

Over the last 20 years (1965-84), cassava production worldwide has increased by over 330 percent. This corresponds to an annual growth rate of 4.3 percent which is substantial for any food crop (Chandra, 1988). Calculated recent changes in world production in 1986 with reference to base year 1984 showed that production of cassava has increased by 5.2 percent, yam by 4.8 percent and taro by 3.7 percent. While world production (including temperate-zone production of sweet potato and potato) has decreased by 3.8 percent and 1.8 percent respectively, the position of these two crops in some developing countries continues to strengthen. Production of sweet potato between 196971 and 1981-83 grew by 3.4 percent per annum in sub-Saharan Africa (FAO, 1986a) and by percentages varying from 6.3 percent per annum (Viet Nam) to 1.1 percent per annum (Thailand) in selected countries of Asia (FAO, 1987b). The increase in potato production for some Asian countries was 7.8 percent per annum for India, 6.2 percent for China, 10.2 percent for Sri Lanka and 13.8 percent for Viet Nam, between 1970-72 and 1982-84. Since 1970 there were also significant gains in potato production in Cuba, Colombia, Venezuela and most of Central America, owing to the adoption of new technologies.

TABLE 3.4 - Ten developing market economies with highest calorie Intake derived from root crops (in percentages)

Nigeria is the highest producer of yams, producing about 73 percent of the world total, most of which is used locally as food. Other leading producers are the West African countries of Cte d'Ivoire (9.2 percent), Ghana (3.4 percent), Benin (2.7 percent), Togo (1.8 percent) and Cameroon (1.6 percent). Virtually all the world production of yam is from West Africa, with D. rotundata the most important variety and D. cayenensis the least important. The other developing countries that produce some yam are in Central and South America, e.g. Haiti, Chile and Ecuador.

The Samoan islanders of the South Pacific region derive nearly 16 percent of their calorie intake from the consumption of cocoyam (aroids), but these root crops are less important in Africa. In Ghana they contribute about 11 percent of calories to the diet but in Nigeria and Cte d'Ivoire their contribution is only about two percent of calorie intake (see Table 3.4.). In Latin America and the Caribbean the production of aroids rose at less than one percent per year between 1969-71 and 1982-84 and did not keep pace with population growth. Similarly in Oceania annual growth in aroid production was sluggish at 1.3 percent and in South and Southeast Asia growth in production during recent years has been negligible.

Mention must be made of banana and plantain which have made a significant contribution to some subsistence economies, especially as the labour cost is relatively lower even than for that of cassava. Labour requirements for the production of various root crops in Nigeria, for example, are shown in Table 3.5.

Plantains and cooking bananas are grown and utilized as a starchy staple mainly in Africa, where production in 1985 was almost 17 million metric tonnes out of total developing-country production of 24 million metric tonnes. Of this total, South American production contributed about 4 million tonnes with the remainder produced in Asia, Central America and Oceania. In most of these regions annual production growth rates between 1969-71 and 1982-84 were only 1.7 to 1.8 percent, and well below the rate of population increase. Although overall production in South and Southeast Asia remained low, the annual rate of growth in production was more

encouraging at 4.9 percent total for both plantain and banana.

TABLE 3.5 - Labour requirements for production of various staple crops in Nigeria

Crop	Working days/ha	Working days/mt	Working days/mcal
Yam	325	45	69.31
Cassava	183	21	20.57
Maize	90	121	35.51
Rice	215	145	59.92

Source: Nweke, 1981.

Cultivation of ensete, Ensete ventricosum, is limited to Ethiopia, where it is a staple food crop of the people of the southern highlands. It resembles a banana plant and is often called the " false banana". It does not produce an edible fruit and is harvested as a food source before flowering. The starchy portions of the swollen pseudo-stem and the underground corm are edible. It has been estimated that between 7 to 8 million people in the south and southwestern part of Ethiopia depend on fermented starchy staples prepared from ensete (FAO, 1985b).

Contents - Previous - Next

Consumption

Contents - Previous - Next

Root crops make an important contribution to the diet of many people in tropical countries, being consumed, as in the case of cassava, as a basic source of low-cost calories, or as a supplement to cereals. The cost of calories from cassava is about 25 to 50 percent that of the locally produced traditional grains and pulses (Goering, 1979), but other root crops, such as yams, are considerably more expensive. In most developing countries the dietary staples consist of starchy foods, which usually include some root crops. As indicated in Table 3.6, tropical roots may supply from as much as 1 060 calories per caput per day, (56 percent of the total daily calorie intake in Zaire), to as little as 200 calories (eight percent of the total daily intake in Belize).

Root crops are consumed not only by adults but are also important items in the diets of children. For example in Ghana and Nigeria infants are often weaned to an adult diet consisting of cassava or plantain. In Zaire, cassava fufu is the second most popular solid food for children under the age of one year, while in Cameroon, cassava is commonly given to infants 6 to 11 months old. Cassava can only form the basis for an adequate diet if it is consumed with other proteinrich foods such as oilseeds, pulses and fish. Young children have a limited stomach capacity and are unable to eat enough bulky foods, such as roots and tubers, to meet their energy needs. The results of a recent survey provide useful data on the frequency of cassava consumption in Zaire. In the survey area,

sweet cassava is eaten raw in some localities as a snack or is boiled as ebe. The bitter varieties of cassava arc made into fuku, a cassava gruel, to which various amounts of corn are added, depending on the season. Mpondu, a vegetable dish made from cassava leaves, is frequently eaten with the fuku. In many areas, fuku with mpondu or other cassava derivatives was eaten about twice a day by over 90 percent of the population in the 24 hours before the interview.

The income elasticity of demand for root crops is low but positive, and the cross elasticities of demand among cereals and root crops are high so substitution is not difficult. A national socio-economic survey conducted in Indonesia in 1980 showed that the per caput consumption of fresh cassava tends to increase as minimal income level increases, but stabilizes or decreases at the higher income levels.

A similar result has been observed in Brazil where the elasticity of demand for cassava is positive at low income levels, and in Ghana where there is no further tendency for the consumption to increase as per caput income increases to levels well above subsistence. In Indonesia, there is a high cross elasticity of demand between cassava and rice. If better production or storage techniques could result in reduced consumer costs of cassava products, then the prospects for an increased consumption of cassava would improve appreciably (Cock, 1985). With some other root crops, especially yams, the consumption tends to increase with rising income as yams are a relatively expensive food. In some places there may also be a strong cultural preference for particular foods, such as sweet potatoes. However, the general tendency is that cereals are preferred to root crops, while wheat and rice are preferred to the coarser grains.

TABLE 3.6 - Tropical root crops as a source of calories In selected countries, 1974

	Population (mid-1975, millions)	GNP unit per caput (market prices, 1975)	Average total calorie consumption (per caput per day)	Calories from root crops)	Percentage of total calories from root crops
Zaire	24.7	140	1 880	1 060	56
Ghana	9.9	590	2 320	870	38
Togo	2.2	250	2 220	850	38
Cte d'Ivoire	6.7	540	2 650	820	31
Nigeria	75.0	340	2 080	540	27
Cameroon	7.4	280	2 370	530	22
Paraguay	2.6	580	2 720	450	17
Madagascar	8.8	200	2 390	370	15
Bolivia	5.6	360	1 850	290	16
Guinea	5.5	130	2 000	290	14
Uganda	11.6	230	2 100	300	14
Peru	15.4	760	2 330	310	13
China (PRO)	822.8	380	2 360	270	12

Indonesia	132.1	220	2 130	250	12
Kenya	13.4	220	2 120	200	9
Brazil	107.0	1030	2 520	230	9
Jamaica	2.0	1110	2 660	230	9
Belize	0.1	670	2 440	200	8

Notes:

Figures rounded to the nearest 10.

Calorie consumption data are from FAO. Population and income figures are from World Bank Atlas, 1977.

Source: Goering, 1979.

As shown in Table 3.7 root crops contribute about 78 percent of the total calorie intake in the Group I region of sub-Saharan Africa, which is mainly in the tropical rain forest belt, and about 43 percent of the total calories in the Group II area, whereas in the more arid zones in Group III, cereals are more prominent. The details of the FAO country classification by groupings for subSaharan Africa are as follows:

***Group I*: Central African Republic, Congo, Mozambique, Zaire. In these countries both production**

and consumption patterns arc dominated by cassava, which accounts for over 50 percent of staple food consumption. Cereals provide 30 percent, and nearly one-third of these are imported.

***Group II*: Angola, Benin, Burundi, Cameroon, Comoros, Equatorial Guinea, Gabon, Ghana, Cte d'Ivoire, Nigeria, Rwanda, Tanzania, Togo, Uganda. A far more diverse production/consumption pattern is prevalent in this group. While roots and plantains are the main staple foods, cassava consumption is much less important than in the previous group. Included here are countries typical of the West African yam-producing belt. While plantains, sweet potatoes and taro are important foods in individual countries cereals account for one-half of calories consumed. Approximately 30 percent of cereals are imported.**

***Group III*: Botswana, Burkina Faso, Cape Verde, Chad, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Namibia, the Niger, Reunion, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Zambia, Zimbabwe. In these countries cereals play a far greater role in both production and consumption, although roots are often staple foods in particular regions. The proportion of cereal consumption met from imports is also generally lower, averaging under one-fifth of the total.**

TABLE 3.7 - Levels of consumption of staple foods In sub-Saharan Africa, 1981-83

	Group I	Group II	Group III	Total
(kg per caput/per annum)				
Starchy	453.4	274.0	45.1	205.1

staples				
Cassava	407.4	123.0	21.3	117.8
Yams	6.6	72.4	3.5	36.8
Sweet potatoes	6.6	20.3	5.0	12.5
Plantains	26.2	39.1	2.0	22.7
Others	6.6	19.2	13.3	15.3
Cereals	39.7	83.8	134.1	98.3
(Percentage, in calorie equivalent)				
Starchy staples	78	49	9	39
Cassava	70	22	4	24
Yams	1	14	1	7
Sweet potatoes	2	3	1	2
Plantains	4	6	-	4
Others	1	4	3	2
Cereals	22	51	91	61

See text for explanation of groups.
Source: FAO, 1987.

In the Pacific root crops still supply from 15 to 43 percent of the dietary energy, the type depending on the island: taro and yam provide 43 percent of the energy in Tonga while sweet potato, taro and yam are the chief suppliers of energy in Papua New Guinea and the Solomon Islands. The difference in cereal and root crops intake between rural and urban areas is striking. The rural population consumes as much as twice the quantity of root crops but less than a tenth of the quantity of cereals than the urban population. This is related to the high cost of transportation and the short shelf-life of fresh root crops. The picture is similar in Latin America and the Caribbean (Table 3.8). In these areas the cost of production of root crops is so high compared to that of cereals that some traditional root crops have become a luxury, except for potato in Bolivia and Peru and cassava in Brazil and Paraguay. In the Caribbean, cereals are definitely more important than roots in the diet though crops like plantain still contribute a substantial part of the dietary energy. In addition, some of the root crops produced are used for animal feed. About 33 percent of the cassava and about three to four percent of the other root crops are used for this purpose.

TABLE 3.8 - Rural/urban consumption of root crops In Latin America and the Carribean, selected crops and countries

	Rural consumption (kg/head/year)	Urban consumption (kg/head/year)

Fresh cassava		
Brazil (1975)	11.2	2.7
Paraguay (1976)	180	35
Colombia (1981)	25.5	8.3
Cuba (1976)	30.0	12.4
Farinha da mandioca		
Brazil (1975)	29.4	9.7
Potato		
Peru (1981)	110	45
Yam		
Colombia (1981)	5.9	2.8

Sources: Lynam, J.K. and Pachico. D.. Fresh cassava in Brazil, Cuba and Paraguay, farinha de mandioca, 1982. Sanint, L.R. et a Z., Fresh cassava and yam in Colombia, 1985. Scott. G.. Potato in Peru, 1985.

Oate et al. (1976) have shown in Table 3.9 that the consumption of root crops in Southeast Asia ranges from 6 kg/caput/year (16 g/caput/day) in Cambodia to 113 kg/caput/year (310 g/caput/day) in Indonesia. The per caput consumption of potato in Singapore is very high (9

kg/year or 25 g/day) compared to the other countries in the region (0 to 7 g/day). Banana makes up a substantial proportion of the Filipino food intake, ranging from 15 g/caput/day in eastern Visayas to 40 g in western Visayas region.

Tables 3.10 and 3.11 show the results of dietary surveys in eight regions in the Philippines varying from the urban population in metropolitan Manila to the rural populations in lowland and mountain areas.

Daily nutrient and food allowances for each individual were obtained from tables prepared by the Food and Nutrition Research Institute. Nutrients in the foods were calculated from food composition tables. Allowances for all members of the household were added together and divided by the number of household members to get the per caput allowances per household. The daily per caput nutrient allowances for each region were obtained by dividing the sum of allowances for all households surveyed in the area by the total number of individuals. Thus the percentages quoted in Table 3.10 give a comparative regional survey of dietary adequacy. The population with the poorest diet in terms of calorie, protein and iron intake is that of eastern Visayas where starchy roots and tubers contribute the bulk of the calories. Table 3.11 shows that the intake of supplementary foods such as legumes, fruit and vegetables, milk, eggs and oils and fats is exceptionally low in this region.

This reinforces the argument that an increased intake of dietary calories from roots and tubers must be supplemented by a variety of other foodstuffs in order to achieve a balanced diet. Studies by Oate et al., 1976, show that in the Philippines the daily consumption of root crops varies with the region, ranging from about eight grams in metropolitan Manila to 222 grams in the rural area

of eastern Visayas. This is true of many countries where food consumption in urban areas is characterized by a decrease in the consumption of root crops and an increase in the consumption of convenience foods from cereals and animal protein (see Table 3.11). The situation is different for processed root products with a relatively high bulk density and an extended shelf-life. In Ghana for example, after fresh cassava is made into dried gari, it can be transported relatively cheaply to the urban areas where it is as popular as in the rural areas. In the case of yarn, surprisingly there is a higher consumption in the urban areas than in the rural areas, indicating the importance of yam as an item of food and reflecting the inflated market price of this preferred root crop as a result of limited production (See Table 3.12).

TABLE 3.9 - Per caput consumption of starchy food In eight Southeast Asian countries (1964 66 average) (thousand tonnes otherwise specified)

TABLE 3.10 - Average daily per caput nutrient Intake In percentage of recommended allowance in eight regions In the Philippines

TABLE 3.11 - Average daily per caput food intake in percentage of recommended allowance in eight regions In the Philippines

In Nigeria, although cassava as dry gari is consumed more in the urban areas than in rural areas the reverse is true with yam, probably because of the expense of transporting fresh yams and the ease of preparing meals using dried gari, which is of great convenience to urban workers (see Table 3.13).

Zones where root crops are consumed do not necessarily coincide with a high incidence of malnutrition. The Indian state of Kerala may serve as an example. This state has a population of about 25 million, whose staple food is rice. However, because of the high population density, fertile land suitable for the cultivation of rice is now in short supply and so most of the rice is cultivated on the poorly drained but fertile lowlands, while the well-drained hilly areas of low fertility are planted mainly with cassava. The main staples arc therefore rice and cassava.

As the population increased rapidly there was less land for the cultivation of rice and the production, yield and consumption of cassava increased.

This might have been expected to adversely affect nutritional status. Taking infant mortality as an index of nutritional status provides reassuring evidence, as the infant mortality in Kerala remained relatively low. Table 3.14 shows that in 1970/71 cassava supplied over 740 calories out of a total daily calorie intake of 2 519, which is probably adequate. Protein intake was less than 40 g per day. Cassava supplied very little but some of this deficit was made up by ingestion of rice and fish. So by varying the diet to include some cereal and animal protein, root crops like cassava are very useful in supplementing the energy obtained from cereals.

This has been confirmed by balance sheet data discussed by Goering (1979) indicating that serious protein deficiency is not necessarily common in countries where root crops arc one of the sources of calories. Thus in ten African countries where root crops supply between 500 to 900 calories or 20 to 40 percent of the total daily caloric intake, seven exhibited a per caput calorie consumption level of under 2 200 cal/day and only one showed an intake greater than 2 400 calories, yet none had a protein intake of less than 40 g per day, and only three had less than 50 g per day. Thus a

limited intake of calories from root crops is not necessarily inconsistent with adequate protein intake.

TABLE 3.12 - Food consumption in Ghana In 1961-62 (g/caput/day)

Food		Urban	Rural	Urban as percentage of rural
Maize	dry grain	10.7	61.1	17.5
	dough	41.2	67.8	60.8
Millet		59.0	44.2	133.5
Guinea corn		14.3	11.6	123.3
Kayo		28.7	6.0	478.3
Rice		21.9	36.6	59.8
Bread		15.9	8.6	184.9
Cassava	fresh roofs	112.2	196.1	57.2
	gari	15.6	16.2	96.3
Plantain		193.5	119.4	162.1
Cocoyam		72.3	44.7	161.7
Yam		110.6	51.6	214.3

Fish	fresh	6.0	11.6	51.7
	smoked	22.0	20.1	109.4
Meat	fresh	41.0	15.2	269.7
	preserved	2.0	2.0	100
Fats and oils		11.7	4.3	272.1
Sugar		4.0	2.1	190.4

Koko is a starchy paste or pap prepared from cereal or root flour.
Source: Calculated from Whitby, P.,A review of information concerning food consumption in Ghana. FAO, Rome. 1969.

Besides root crops, the leaves of cassava, sweet potato and cocoyam are commonly consumed in many tropical countries including Zaire, Papua New Guinea and central Java in Indonesia, especially during periods of food shortage. These leaves contribute some protein to the diet. They also contain minerals, particularly iron and calcium, and provide a valuable source of vitamins A and C. Increased consumption of these green leaves could help reduce the incidence of xerophthalmia in countries where nutritional blindness is prevalent. The use of edible cassava leaves as a green vegetable is popular in Africa (Hahn, 1984).

TABLE 3.13 - Food consumption In Nigeria (g/caput/day)

Food	Rural	Urban	Urban as a percentage

			of rural
Yam, fresh tuber	287.8	70.0	24
Cassava, dry gari	43.1	141.0	327
Cocoyam, fresh	33.8	-	
Irish potato	31.8	-	
Plantain, boiled fruit	13.5	9.0	68
dry flour	10.3	-	
Taro, boiled	16.7	-	
Maize, meal	162.8	-	
grain	27.3	-	
dry starch	17.0	36.0	211
Millet,	meal 88.8	4.0	
	fura 16.8	-	
Guinea corn, meal	16.4	-	
Acha, grain	22.0	-	
Rice	11.7	47.0	401
Wheat	1.3	31.0	2 384

Cowpea	21.9	33.0	150
Locust bean	13.8	-	
Beef	23.3	35.0	150
Fish, dry	3.5	5.0	142
Red palm oil	27.7	20.0	72
Cows milk, fresh	35.2	6.0	17
Sugar	4.4	5.0	113
Fish, fresh	-	58.0	5 800
Egg	-	4.0	400

Rural figures based on studies by Collis, Dema, Lesi & Omololu (1962).
Urban figures calculated on the basis of a study by McFie (1967) in Lagos.

TABLE 3.14 - Food consumption in Kerala, 1970/71 (average daily per caput value)

Food	Total consumption (g)	Calories	Protein (g)
Rice	289	1 000	18.5
Cassava (tapioca)	474	744	3.3
	60	267	2.7

Coconuts Fruit	87	68	0.7
Fish	41	46	8.3
Milk	30	23	1.0
Meat	5	6	1.1
Oil	24	212	-
Sugar	25	100	-
Subtotal		2 466	35.6
All other		53	2.2
Total		2 519	37.8

Source: United Nations, 1975.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

4. Nutritive value

Contents - Previous - Next

The main nutritional value of roots and tubers lies in their potential ability to provide one of the cheapest sources of dietary energy, in the form of carbohydrates, in developing countries. This energy is about one-third of that of an equivalent weight of grain, such as rice or wheat, because tubers have a high water content. However, the high yields of most root crops ensure an energy output per hectare per day which is considerably higher than that of grains (see Table 4.1). Sweet potato for example has a tremendous capacity for producing high yields, up to 85 t/ha have been recorded on experimental plots, though most plantation yields do not exceed 20 t/ha. As shown in Table 4. 1, potato is one of the highest calorie-yielding crops in the world. Such root crops are particularly valuable in the tropics where most of the population depends on carbohydrate foods as dietary staples.

Because of the low energy content of root crops compared to cereals on a wet basis, it is often assumed that root crops are not suitable for use in baby foods. This is not necessarily true if their energy density is increased by drying. Tapioca, for instance, is used in a number of commercial baby foods in industrialized countries. Composite flours prepared from root crops and cereals could be used in baby food formulas, if appropriately supplemented. The addition of germinated (malted) cereals to cassava flour increases the energy density of gruels prepared from it, by reducing their viscosity through the action of amylolytic enzymes. However, the use of fresh cassava products as infant weaning foods should be discouraged, because of probable toxicity, low protein content and energy density. Infants and young children, pregnant and lactating women are among the most nutritionally vulnerable people. Their nutrient requirements are specifically higher in order to meet the increased physiological demand for growth and lactation.

These requirements are listed in Tables 4.2 and 4.3 together with those for adolescents and adults.

TABLE 4.1 - Comparison average energy and protein production of selected food crops In developing countries (per hectare and per day)

Crop	Growth duration (days)	Dry matter (kg/ha/day)	Edible energy ('000 kcal/ha/day)	Edible protein (kg/ha/day)	Production value (US$/ ha/day
Potato	130	18	54	1.5	12.60
Yam	180	14	47	1.0	8.80
Sweet potato	180	22	70	1.0	6.70
Rice, paddy	145	18	49	0.9	3.40
Groundnut in shell	115	8	36	1.7	2.60
Wheat	115	14	40	1.6	2.30
Lentil	105	6	23	1.6	2.30
Cassava	272	13	27	0.1	2.20

Source: FAO, Production yearbook 1983 (Rome 1984), USDA Composition of foods (Washington,

D.C. 1975) and FAO, Report of the agroecological zones project (Rome, 19;8). Production estimates arc 1981-83 averages; price estimates are for 1977.
Adapted and modified from Horton et al., (1984).

Undernutrition is often the outcome of either an insufficient food intake or poor utilization of food by the body, or both simultaneously. Recent surveys show that very few people in tropical countries suffer from a simple protein deficiency. The most prevalent deficiency is protein-energy, in which an overall energy deficiency forces the metabolism to utilize the limited intake of protein as a source of energy. This is an area in which root crops could play a more significant role as additional sources of dietary energy and protein. Increasing the consumption of root crops could help save the much-needed protein provided essentially by other foods such as cereals and legumes. Traditionally, in Africa, root crops such as cassava are eaten with a soup or stew made of fish, meat or vegetables, providing an excellent supplement to cassava meal.

TABLE 4.2 - Average dally energy, protein, vitamin A, folic acid, Iron and iodine requirements for Infants and children

Age	**Median weight (kg)**	**Energy (kcal)**	**Protein (g)**	**Vitamin A (mg)**	**Folic acid (mg)**	**Iron (mg)**	**Iodine (mg)**
Infants (months)							
3-6	7.0	700	13.0	350	25	14	40

6-9	8.5	810		14.0	350	31	14	50
9-12	9.5	950		14.0	350	34	14	50
Children (years)								
1-2	11.0	1 150		13.5	400	36	8	70
1-3	13.5	1 350		15.5	400	46	9	70
3-5	16.5	1 550		17.5	400	54	9	90
		boys	girls					
5-7	20.5	1 850	1 750	21.0	400	68	9	90
7-10	27.0	2100	1 800	27.0	400	89	16	120

Notes:
Values derived from Energy and protein requirements: report of a joint FAO/WHO/UNU expert consultation. WHO Technical Report Series 724. Geneva, 1985.
Values derived from Requirements of vitamin A, iron, folate and vitamin B12: report of o joint FAO/WHO Expert Consultation (In press)
Values derived from Recommended dietary allowances: Ninth rev. ea., US National Academy of Sciences. Washington, D.C., 1980.
Source: FAO, 1988b.

TABLE 4.3 - Average daily energy, protein, vitamin A, folic Iron and iodine requirements for adolescents and adults

Age (years)	Median weight (kg)	Energy (kcal)	Protein A (g)	Vitamin acid (mg)	Folic (mg)	Iron (mg)	Iodine (mg)
Males							
10-12	34.5	2.200	34.0	500	102	16	150
12-14	44.0	2400	43.0	600	170	24	150
14-16	55.5	2 650	52.0	600	170	24	150
16-18	64.0	2 850	56.0	600	200	15	150
>18	70.0	3 050	52.5	600	200	15	150
Females							
10-12	36.0	1 950	36.0	500	102	16	150
12-14	46.5	2100	44.0	600	170	27	150
14-16	52.0	2150	46.0	600	170	27	150
16-18	54.0	2150	42.0	500	170	29	150
>18	55.0	2 350	41.0	500	170	29	150

Pregnant full activity		+285	+6.0	600	370-470	47[4]	+25
reduced activity		+200	+6.0	600	370-470	47[4]	+25
Lactating							
first 6 months		+500	+17.5	850	270	17	+50
after 6 months		+500	+13.0	850	270	17	+50

Notes:
Values derived from Energy and protein requirements: report of a joint FAO/WHO/UNU expert consultation. WHO Technical Report Series 724. Geneva, 1985.
Values derived from Requirements of vitamin A, iron, folate and vitamin B.': report of a joint FAO/WHO Expert Consultations. (In press)
Values derived from Recommended dietary allwances. Ninth rev. ea., US National Academy of Sciences. Washington, D.C., 1980.
[4]Among pregnant women, dietary supplementation of iron is usually called for because the iron requirement cannot be met through normal dietary intake.
+ In addition to the normal requirement.
Source: FAO, 1988b.

Nutritional composition of roots and tubers

As with all crops, the nutritional composition of roots and tubers varies from place to place depending on the climate, the soil, the crop variety and other factors. Table 4.4 shows the nutritional composition for common roots and tubers and the amino-acid composition of some root crop proteins along with a comparison of suggested amino-acid requirement is shown in Table 4.5.

The main nutrient supplied by roots and tubers is dietary energy provided by carbohydrates. The protein content is low (one to two percent) and in almost all root crop proteins, as in legume proteins, sulphur-containing amino-acids are the limiting amino-acids (Tables 4.5, 4.9). Cassava, sweet potato, potato and yam contain some vitamin C and yellow varieties of sweet potato, yam and cassava contain beta-carotene or provitamin A. Taro is a good source of potassium. Roots and tubers are deficient in most other vitamins and minerals but contain significant amounts of dietary fibre. Leaves of taro are cooked and eaten as a vegetable. They contain betacarotene, iron and folic acid, which protects against anaemia. Leaves of sweet potato and cassava are also commonly eaten.

Carbohydrates

The dry matter of root crops, banana and plantain is made up mainly of carbohydrate, usually 60 to 90 percent. Plant carbohydrates include celluloses, gums and starches, but starches are the main source of nutritive energy as celluloses are not digested.

Starches are made up of two main polymers, a straight chain glucose polymer called amylose,

which usually constitutes about 10 to 30 percent of the total, and the branched chain glucose polymer, amylopectin, which makes up the rest. The principal constituent of edible carbohydrate is starch together with some sugars, the proportion depending on the root crop.

The physical properties of starch grains influence the digestibility and processing qualities of root crops. The starch granules of some varieties of cocoyam are very small, about one-tenth those of potato, which improves the starch digestibility, making these varieties more suitable for the diets of infants and invalids. For the preparation of certain foods like fufu, a stiff dough is required and so the rheological properties of the starch paste become significant. The viscosity of starch-water pastes of different yam starches varies considerably from a relatively low value for D. dumetorum through increasing viscosity in D. esculenta to the highest value in D. rotundata (see Table 4.6). Hence D. rotundata is traditionally the accepted yam for fufu. Most yams give viscous pastes with a much higher gel strength than that of other crops. Therefore yams are traditionally preferred for fufu, a starch paste which is prepared by pounding cooked roots or tubers in a mortar with a pestle (Rasper, 1969, 1971). Cassava starch has some special characteristics for food processors. It is readily gelatinized by cooking with water and the solution after cooling remains comparatively fluid. The solutions are relatively stable and do not separate again into an insoluble form (retrogradation) as is the case with maize and potato starch.

In addition to starch and sugar, root crops also contain some non-starch polysaccharides, including celluloses, pectins and hemicelluloses, as well as other associated structural proteins and lignins, which are collectively referred to as dietary fibre (Table 4.7). The role of dietary fibre in nutrition has aroused a lot of interest in recent years. Some epidemiological evidence suggests that increased fibre consumption may contribute to a reduction in the incidence of certain

diseases, including diabetes, coronary heart disease, colon cancer, and various digestive disorders. The fibre appears to act as a molecular sieve, trapping carcinogens which would otherwise have been recirculated into the body; it also absorbs water thus producing soft and bulky stools. Sweet potato is a significant source of dietary fibre as its pectin content can be as high as 5 percent of the fresh weight or 20 percent of the dry matter at harvest (Collins and Walter, 1982). However, banana, which is also known to have a beneficial effect in correcting intestinal disorders, appears to contain very little dietary fibre, only 0.84 percent using traditional methods of analysis. Because of this, Forsythe (1980) carried out some studies on the cell wall materials of banana pulp by extracting with ascorbic acid, centrifuging and washing the sugars away. The residue, comprising 3.3 percent of the pulp had a water-holding capacity 17 times its dry weight. Analysis yielded 15.2 percent lignin, 13 percent starch, 9.8 percent protein, 4.8 percent cellulose, 3.7 percent lipid, 1.3 percent pectin and 0.4 percent ash. There is therefore a need to pay more attention to the significance of fibrous components in these root crops, especially in banana and sweet potato, and to determine their composition and dietary function. Other root crops, particularly yam, contain mucilages, which have a considerable influence on their cooking qualities.

TABLE 4.4 - Nutritive values of tropical root crops (per 100 9 edible portion)

TABLE 4.5 - Comparison of suggested amino-acid requirement patterns with amino-acid composition of tropical root crops

TABLE 4.6 - Rheological properties of various yam starches

	Viscosity (Brabender units)	Gel strength (ml)

				after		
Species and cultivar	Pasting temp. C	(on attaining 95C)	(maximum reached before cooling)	24 h	96 h	168 h
D. rotundata						
Puna	76	450	630	8.8	13.6	14.1
Labreko	78-79	260	470	4.3	6.2	8.0
Kplinjo	77	330	490	10.6	12.7	13.3
Tantanpruka	79	610	650	12.4	17.2	20.5
Tempi	80-82	430	520	7.5	10.6	10.8
D. alata						
White fleshed	85	25	110	14.8	16.5	17.2
Purple fleshed	81	80	200	14.8	18.5	19.4
D. esculenta	82	25	55	2.5	4.0	4.6
D. dumetorum	82	25	25	-	-	-

Source: Rasper and Coursey (1967).

TABLE 4.7 - Fibre as percentage of dry matter in raw sweet potato and banana

	Sweet potato	Banana
Cellulose	3.26	1.0
Hemicellulose	4.95	5.8
Insoluble pectin	0.60	-
Lignin	NR	0.2

TABLE 4.8 - Calorie and protein contribution of starchy staples to diets in developing country regions, (in percentage of regional total) 1979-81

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Protein

Contents - Previous - Next

The protein content and quality of roots, tubers, bananas and plantains are variable; that of yam and potato is highest, being approximately 2.1 percent on a fresh weight basis. The protein contribution of these foods to the diet in developing countries, corrected by the amino-acid protein quality is, on a worldwide average, only 2.7 percent, provided mainly by potato and sweet potato. However these starchy staples do provide a much greater proportion of the protein intake in Africa (Table 4.8), ranging from 5.9 percent in East and southern Africa to a maximum of 15.9 percent in humid West Africa, supplied mainly by yam and cassava. These figures do not include the protein contribution from the leaves of crops such as cassava, sweet potato and cocoyam which are eaten as green vegetables. The amino-acid content of roots and tubers, unlike most cereals, is not complemented by that of legumes as both are limiting in respect of the sulphur amino-acids (see Table 4.9). In order to maximize their protein contribution to the diet, roots and tubers should be supplemented with a wide variety of other foods, including cereals.

To some extent the protein content of root crops is influenced by variety, cultivation practice, climate, growing season and location (Woolfe, 1987). In potato, the addition of nitrogen fertilizer increases the protein content (Eppeudorfer et al., 1979; Hoff et al., 1971) while in the case of sweet potato the protein content could vary from 2.0 to 7.5 percent depending on the cultivar and treatment. Nitrogen fertilizer increases the protein content of sweet potato, but the lysine content is decreased, while the aspartic acid and free amino-acids are increased (Yang, 1982). Also leafy growth is increased at the expense of tuber production.

In root crops the quality of the protein, in terms of the balance of essential amino-acids present, may be compared to that of standard animal proteins in beef, egg or milk (see Table 4.5). Most root crops contain a reasonable amount of lysine, though less than in legumes, but the sulphur

amino-acids are limiting. For example, yam is rich in phenylalanine and threonine but limiting in the sulphur amino-acids, cystine and methionine and in tryptophan.

Protein quality may be assessed in terms of the amino-acid score but the biological utilization of protein depends also on the composition of the diet, the protein digestibility and the presence of toxins or other antinutritional factors. This is reflected in the net protein utilization (NPU) proportions of nitrogen intake that is retained or biological value (BV) of the protein, which estimates the proportion of absorbed nitrogen that is retained (Table 4.10) either by measurement of nitrogen balance, or preferably by direct studies on experimental animals. Results may also be expressed as protein efficiency ratios (PER values) where PER = gain in weight in grams divided by the protein intake in grams.

In feeding studies conducted on rats, banana proteins were utilized as well as those of maize, although their utilization was less efficient than those of yam, cocoyam and sweet potato. The protein of potato is of good nutritional quality with a relatively high lysine content, and so it can be used in developing countries to complement foods low in lysine. As shown in Table 4.10, its utilizable protein as a percentage of its calorie content is as high as that of wheat.

The protein of sweet potato is also of acceptable nutritive value, with a chemical score of 82 and sulphur amino-acids as the major limiting factors. The quality of the protein will depend on the severity of heat treatment during the processing of sweet potato products. (Walter et al., 1983). Horigone et al., (1972) reported a PER of 1.9 for a protein isolated from a sweet potato starch production factory. This value could be increased to 2.5 by the addition of lysine and methionine, indicating a deficiency of methionine and the destruction of lysine during processing. When

unheated sweet potato flour was added to wheat in the diet of rats at the 30 percent level, the biological value of the diet was increased from 72 to 80 owing to the improved protein value. A similar result was obtained when sweet potato flour replaced rice (Yang, 1982). Walter and Catignani (1981) extracted a white protein isolate and a grayish-white protein concentrate (chromoplast protein) from two sweet potato varieties, "Jewel" and "Centennial" and found that they gave a very good amino-acid pattern, with lysine higher than the FAO pattern (Table 4.11). Both the isolates gave a higher gain in weight and a better PER than casein, though this was not statistically significant, indicating that some protein fractions from selected varieties of sweet potato are of very high quality (Yang, 1982).

Cassava protein is lower in total essential amino-acids than the other root crops but recently Adewusi et al. (1988) found that cassava flour used as a component in animal feeding trials was a more effective replacement for wheat than either sorghum or maize. The content of protein in yam varies between 1.3 and 3.3 percent, (Francis et al., 1975), but based on the quantity consumed by an adult in West Africa, about 0.5 to 1 kg per caput/day, it can contribute about six percent of the daily protein intake (see Table 4.8). The chemical score for yam proteins, using the FAO reference protein as standard, varied from 57 to 69 (Francis et al., 1975). The incidence of kwashiorkor has been reported to be high in yam consuming areas. This emphasizes the need to supplement a yarn-based diet with more protein-rich foods in order to support active growth in infants. Fresh cocoyam contains a high percentage of water and is a food of low energy density compared to alternative root crops. It has a protein content of about two percent (Table 4.4) with a chemical score of 70 (Table 4.5). However chemical score alone is not a satisfactory index of protein availability and efficiency in the diet. This can best be assessed by controlled feeding trials

to obtain values of digestibility. Such values have been determined for many individual foods. If information is not available on the digestibility of the protein in a particular diet, the value can be estimated by using values for individual components and calculating a weighted mean according to the proportion of protein supplied by these foods. In foods of low protein content such as yam and cassava, feeding trials to determine the biological efficiency of the protein are often inconclusive. As an approximate correction, for a diet based on vegetable protein, a digestibility factor of 85 percent may be applied (WHO, 1985).

TABLE 4.9 - Essential amino-acids of plantain, cassava, sweet potato, cocoyam and yam compared with cowpea

Amino-acids (mg N/g)	Plantain	Cassava	Sweet potato	Cocoyam	Yam	Cowpee
Lysine	193	259	214	241	256	427
Threonine	141	165	236	257	225	225
Tyrosine	89	100	146	226	210	163
Phenylalanine	134	156	241	316	300	323
Valine	167	209	283	382	291	283
Tryptophan	89	72	-	88	80	68
Isoleucine	116	175	230	219	234	239
Methionine	48	83	106	84	100	73

Cystine	65	90	69	163	72	68
Total sulphur-containing	113	173	175	247	172	141
Total	1 042	1 309	-	1 976	1 768	1 869

Source: FAO, 1970.

TABLE 4.10 - Utilizable protein In some staple foods (percentage of calories)

	Total protein	Utilizable protein
Sago	0.6	0.3
Cassava	1.8	0.9
Plantain	3.1	1.6
Yam	7.7	4.6
Maize	11.0	4.7
Rice	9.0	4.9
Potato	10.0	5.9
Wheat	13.4	5.9

Source: Payne, 1969.

TABLE 4.11 Comparison of essential amino-acid patterns for chromoplast and white protein In Jewel and Centennial sweet potato roots to the FAO reference protein

Aminoacid	Chromoplast		FAO	White	
	Jewel	Centennial		Jewel	Centennial
Threonine	5.77	5.67	4.0	6.43	6.39
Valine	7.83	7.68	5.0	7.90	7.89
Methionine	2.26	2.10		2.03	1.84
Isoleucine	6.01	5.89	4.0	5.63	5.71
Leucine	9.64	8.95	7.0	7.40	7.44
Tyrosine	6.71	6.41	6.0	6.91	7.09
Phenylalanine	7.08	7.15		8.19	7.94
Lysine	7.03	6.43	5.5	5.16	5.21
Tryptophan	1.56	1.77	1.0	1.23	1.44
PER	2.73	2.78		2.64	2.63

g amino-acid/16 g N

Source: Walter and Catignani, 1981.

Human dietary tests have been carried out using root crops to test the efficiency of the root crop protein to maintain good health in the absence of other protein sources. Most of this work has been done on potato and is well documented by Woolfe (1987). The classical work of Rose and Cooper (1907) indicated that young women could be maintained in nitrogen balance for seven days on a diet in which potato supplied 0.096 g N/kg body weight. This has been confirmed more recently in experiments in which a potato protein level of 0.0545 g/kg body weight was found to maintain nitrogen balance in healthy college students, compared to a value of 0.0505 g/kg body weight obtained for egg.

Lopez de Romana et al. (1981) in Peru reported that potato can be used successfully to supply up to 80 percent of the daily requirement of protein and SO to 75 percent of the energy of infants and young children if the remaining energy and nitrogen is provided by a non-bulky, easily digestible food. Acceptability, digestibility, tolerance and growth of children were analysed. Excellent acceptability and tolerance were found for a diet providing about 50 percent of the energy from potato with casein added to make up to 80 percent of the total dietary energy from protein. Raising the level of potato to provide 75 percent of the dietary energy tends towards poor acceptability and tolerance near the last week of the three-month study mainly because of the bulk and the poor digestibility of the carbohydrates.

When the British settled on the remote South Pacific Island of Tristan da Cunha in 1876, it was reported in 1909 that the population had increased and were very healthy on a potato-based diet, consuming about 3-4 lb of potatoes per day (Kahn 1985). Even in an affluent country such as

the United Kingdom, potato contributed about 3.4 percent of the total household protein intake according to the National Food Survey Committee (1983), compared to 1.3 percent for fruit, 4.6 percent for egg, 4.8 percent for fish, 5.8 percent for cheese, 5.7 percent for beef, 9.8 percent for white bread and 14.6 percent for milk.

In dietary tests adult Yami tribesmen were given a diet based on sweet potato supplemented with fish and vegetables, designed to supply 0.63 g protein/kg body weight/day. They did not show any physical abnormality after two months, but appeared to tire more easily after a more prolonged period on this diet. As a result of the high dietary fibre content the faecal volume of the test subjects was very high, an average of 800 g on a wet weight basis per day. This diet, contrary to expectation, did not generally reduce the serum cholesterol and total lipids, as did some other vegetables, though a particular sweet potato variety did significantly reduce these factors (Yang, 1982).

However, when seven teenage boys were placed on two similar diets based on sweet potato, supplying 0.67 g protein and 0.71 g protein kg body weight respectively, they exhibited a negative nitrogen balance and their plasma urea nitrogen decreased from 8-11 mg to 2-3 mg per 100 ml. Their plasma free amino-acid pattern also showed some abnormalities, with the branched chain amino-acids, valine, isoleucine and leucine values decreasing, indicating some degree of protein depletion (Huang, 1982). This finding confirms that sweet potato protein alone cannot meet adequately the nutritional requirements of a growing child, but appears to be more promising in the case of adults. In an attempt to improve the diets of the people of Taiwan, Yang (1982) found that when 13 percent of sweet potato was substituted equicalorically for rice in the Taiwanese diet, the nitrogen balance was improved to complementarily of the proteins. The same

replacement was found to prolong the longevity of tested male and female rats. Thus, if it can be produced at a competitive price, sweet potato can provide a supplementary staple for rice, wheat flour and other cereals.

Food containing about 5 percent of total energy provided by utilizable, balanced protein can sustain health if it can be eaten in sufficient quantities to meet energy requirements. It is therefore important to review the factors affecting the protein content of root crops. If varieties with a high protein content and good carbohydrate digestibility could be developed these could be used in the formulation and production of supplementary weaning foods. Experimental production of weaning foods containing potato has been reported by Abrahamsson (1978). Breeding programmes for improved protein, vitamin or mineral content in food crops should also include consumer preference studies, to ensure acceptance of the improved varieties at producer level.

Lipids

All the root crops exhibit a very low lipid content. These are mainly structural lipids of the cell membrane which enhance cellular integrity, offer resistance to bruising and help to reduce enzymic browning (Mondy and Mueller, 1977) and are of limited nutritional importance. The content ranges from 0.12 percent in banana to about 2.7 percent in sweet potato. The lipid may probably contribute to the palatability of the root crops. Most of the lipid consists of equal amounts of unsaturated fatty acids, linoleic and linolenic acids and the saturated fatty acids, stearic acid and palmitic acid. In dehydrated products such as dehydrated potato or instant

potato, the high percentage of unsaturated fatty acids in the lipid fraction may accelerate rancidity and auto-oxidation, thereby producing off-flavours and odour. The low fat content of plantain, coupled with its high starch content, makes it an ideal food for geriatric patients. Banana is the only raw fruit permitted for people suffering from gastric ulcer, and is also recommended for infantile diarrhea. Banana is also used as a source of carbohydrate in coeliac disease and in the relief of colitis.

Vitamins

Since roots and tubers are very low in lipid they are not in themselves rich sources of fat-soluble vitamins. However, provitamin A is present as the pigment beta-carotene in the leaves of root crops, some of which are edible. Most roots and tubers contain only negligible amounts of beta carotenes with the exception of selected varieties of sweet potato. Deep coloured varieties are richer in carotenes than white cultivars. In the orange variety "Goldrush", the pigment is made up of about 90 percent beta carotene and in "Centennial" the corresponding figure is 88 percent. This is one of the nutritional advantages of sweet potato because sufficient and regular ingestion of sweet potato leaves, together with the tubers of high beta-carotene varieties can meet the consumer's daily requirement of vitamin A, and hence prevent the dreadful disease of xerophthalmia, which is responsible for nutritional blindness in many sub-Saharan countries and in Asia. The dessert type of sweet potato is even higher in beta-carotene and it has been estimated that an intake of 13 g/day will be sufficient to meet the vitamin A requirement. Similarly some varieties of yam are highly coloured, especially D. cayenensis, called yellow yam. The colour of yellow yam is also because of carotenoids, consisting mainly of beta-carotene in

quantities of 0.14-1.4 mg per 100 g (Murtin and Rubert, 1972) and other carotenoids which have no nutritional significance (Martin et al., 1974b). Some Pacific Island varieties of yam contain up to 6 mg per 100 g (Coursey, 1967) of carotene; cocoyam also has a generous amount. Other sources of beta-carotene include the deep orange varieties of banana. The concentration, however, decreases from 1.04 mg per 100 g when green (unripe) to 0.66 mg when ripe (Asenjo and Porrata, 1956). Plantain contains very little beta-carotene.

Potato has no vitamin A activity. There is some report of the occurrence of some vitamin E, up to 4 mg per 100 g in sweet potato.

Vitamin C occurs in appreciable amounts in several root crops. The level may be reduced during cooking unless skins and cooking water are utilized. Root crops, if correctly prepared, can make a significant contribution to the vitamin C content of the diet. Banana contains about 10-25 mg of vitamin C per 100 g, though figures as high as 50 mg have been quoted in some varieties. The quantity is the same whether it is ripe or unripe. Yam contains 6-10 mg of vitamin C per 100 g and up to 21 mg in some cases. The vitamin C content of potato is very similar to those of sweet potato, cassava and plantain, but the concentration varies with the species, location, crop year, maturity at harvest, soil, nitrogen and phosphate fertilizers (Augustin et al., 1975). One hundred grams of potato boiled with the skin is sufficient to provide about 80 percent of the vitamin C requirement of a child and 50 percent of that for an adult. According to the 1983 Nutritional Food Survey Committee, potato was a principal source of vitamin C in British diets, providing 19.4 percent of the total requirement. McCay et al. (1975) estimated that in the United States of America potato provided as much vitamin C (20 percent) as did fruits (18 percent).

Most of the root crops contain small amounts of the vitamin B group, sufficient to supplement normal dietary sources. The B-group of vitamins acts as a co-factor in enzyme systems involved in the oxidation of food and the production of energy. These vitamins are found mainly in cereals, milk and milk products, meat and green vegetables, including the leaves of roots and tubers. For every 1 000 kcal of carbohydrate ingested about 0.4 mg of vitamin B. (thiamine) is needed for proper digestion. Sweet potato contains about double this required amount of vitamin B. (0.8-1.0 mg/1 000 kcals). Villareal (1982) has estimated that a hectare of land planted with sweet potato will provide about eight times as much vitamin B1 (thiamin) and 11 times as much vitamin B2 (riboflavin) as a hectare planted with rice (see table 4. 12). Similarly it has been estimated by the Nutrition Food Survey Committee (1983) that in the United Kingdom potato supplied 8.7 percent of the riboflavin, 10.6 percent of the niacin (vitamin B3), 12 percent of the folic acid, 28 percent of the pyridoxine (vitamin B6) and 11 percent of the panthothenic acid (Finglas and Faulks, 1985).

TABLE 4.12 Number of persons a hectare of crop can support per day In terms of different nutrients

Crop	Calories	Calcium	Iran	Vitamin A	Thiamin	Riboflavin	Vitamin C
Rice	61	2	33	0	18	9	0
Maize	27	1	9	25	42	24	480
Sweet potato	135	138	405	991	140	106	1 370
roots							
	122	85	105	324	100	40	1 050

leaves	15	53	300	667	40	66	320
Taro	55	86	178	770	120	61	660
corms	45	28	71	0	107	24	180
loaves	6	40	65	747	10	33	433
petiole	3	16	40	23	1	3	46
Cabbage	41	178	194	50	92	74	3 441
Mungo	29	17	78	4	60	20	27
pod	42	159	150	347	158	168	1 008
dry been	63	18	193	0	129	61	0
Soybean (dry)	33	41	168	0	40	16	trace
Soybean (green)	36	87	194	6	1 257	614	251
Mango	1	0	501	18	1	1	279
Tomato	16	26	116	257	58	38	845
Banana	2	110	2	1	0	2	237

Source: Villareal, 1970

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Minerals

Contents - Previous - Next

Potassium is the major mineral in most root crops while sodium tends to be low. This makes some root crops particularly valuable in the diet of patients with high blood pressure, who have to restrict their sodium intake. In such cases the high potassium to sodium ratio may be an additional benefit (Meneely and Battarblee, 1976). However, high potassium foods are usually omitted in the diet of people with renal failure (McCay et al., 1975). As root crops are low in physic acid relative to cereals, those minerals liable to inactivation by dietary physic acid are more available than in cereals. This is especially important for iron, which has been found to be 100 percent available in banana (Marriott and Lancaster, 1983). In addition the high vitamin C concentration in some root crops may help to render soluble the iron and make it more available than in cereals and other vegetable foods. In the United Kingdom the iron supply from potato ranks third of all individual food sources, accounting for up to 7 percent of the total household dietary iron intake. True e, al. (1978) found that 150 g of potato will supply 2.3 to 19.3 percent of the dietary requirement for iron recommended by the Food and Nutrition Board of the National Research Council of America. there is some doubt about the availability of calcium and phosphorus in cocoyam owing to the oxalate content.

An important, often unrecognized, mineral contribution that potato can make is in the appreciable amount of iodine it contains. This could be significant in goitrous areas of Africa and Asia where iodine intake is low or marginal. Since over 96 percent of the zinc in potato is available, again due to low levels of phytate, potato can also significantly contribute this mineral. Yam can supply a substantial portion of the manganese and phosphorus requirement of adults and to a lesser extent the copper and magnesium. As indicated in Table 4.12, a hectare of sweet potato will provide the calcium requirement for 60 times as many people and 12 times the requirement of iron as the same area of land planted with rice.

Root crop leaves

Apart from the yellow variety of sweet potato, which contains a high amount of beta-carotenes (up to 30 mg retinol equivalent percent) most of the other root crops contain only negligible amounts. However, their leaves contain a substantial amount of beta-carotenes that could contribute significantly to the daily requirement of vitamin A, especially for children, thereby helping to eradicate the ocular diseases affecting about six to eight million children from Asia, Africa and Latin America. Dietary retinol obtained from the consumption of animal foods is relatively expensive and contributes about 14 and 20 percent to the vitamin A intake of people in Asia and Africa respectively. Beta-carotenes from leaves such as sweet potato or cassava, which contain about 800 mg/100 g and which is about the same as beef liver, contribute as much as 86 percent in Asia and 80 percent in Africa.

The quantity of root crop leaves required to meet the average daily requirement of retinol differs

considerably, with Cassava requiring only 50 g, dark green vegetable leaves 73 g, sweet potato leaves 78 g and taro leaves 133 g.

Cassava leaves have a crude protein content of 20-35 percent on a dry weight basis. The quality of the leaf protein is generally good though it is deficient in methionine. Cassava leaves are low in crude fibre and relatively high in calcium and phosphorus. Cassava varieties in which the tuber contains cyanogenic glycosides usually show a similar content in their leaves.

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5. Methods of cooking and processing

Like many other foods, roots and tubers are rarely eaten raw. They normally undergo some form of processing and cooking before consumption. The methods of processing and cooking range from simple boiling to elaborate fermentation, drying and grinding to make flour, depending on the varieties of roots and tubers.

The basic purpose of these methods is to make roots and tubers and their products more palatable and digestible and to make them safe for human consumption. Processing also extends the storage life of roots and tubers, which are often highly perishable in their fresh condition. Processing also provides a variety of products which are more convenient to cook, prepare and consume than the original raw materials.

Women play a very active role in all the stages involved in the production and processing of root

crops. Assessment from five states in Nigeria indicated that in cassava production women on average complete 34 percent of the field preparation and 77 percent of the planting of cassava, 86 percent of the weeding and 77 percent of the harvesting. The post-harvest activities of processing, storage and marketing, are undertaken mainly by women, though recent studies indicate that men are beginning to take an interest in the processing of root crops through the purchasing and management of electrically operated grinding machines.

Cassava

Although raw sweet cassava is occasionally eaten in the Congo region, Tanzania and West Africa, cassava is not generally consumed raw. A large variety of processing techniques have been developed in different parts of the world resulting in a wide variety of products. Those techniques serve not only to render the root palatable, and in many cases storable, but they also have the effect of eliminating or reducing cyanide (HCN) content to acceptable levels. Many processes such as soaking and fermenting have been designed specifically to detoxify the root. Others, such as boiling and roasting are designed to make cassava products more palatable. The degree of reduction of cyanide in the final product varies greatly with the type of processing techniques used. Many of the complex techniques used around the world today originated in South America and were introduced to the other regions with the cassava plant, or in some cases at a later date. Other processes have been developed independently in the producing countries.

Roasting, boiling, frying

In Latin America roasting is the simplest technique, but it is not commonly practiced. It is used only when no cooking utensil is available. The whole roots are buried in hot ashes or placed in front of the fire until cooked through.

Sweet cassava roots are more often prepared by boiling and are eaten either hot or cold or sometimes mashed. These are general methods all over the world. In Latin America, a soup or stew called cancocho or cocido is prepared by boiling cassava roots with vegetables. The technique of deep frying cassava in fat is thought to have been introduced by Europeans. In Uganda, the roots are peeled, washed, wrapped in banana leaves and steamed in a pan (Goode, 1974). Roasting sweet cassava in ashes is widely practiced in Africa. In South Africa, bitter varieties are also roasted but are first peeled and rubbed with tobacco. In Zambia roots are often soaked before roasting. Fried cassava is prepared after peeling, by washing, slicing and then frying in oil.

Grating, pounding, baking, or boiling

In Latin America, cassava roots arc grated on spiny palm trunks or pounded into a pulp. The pulp is then squeezed by hand and cooked in a variety of ways. Several groups shape the pulp into pies or cakes which are then baked in hot ashes, sometimes being wrapped in a protective covering of leaves before baking. Some groups, such as the Nambicuara, sun dry the pulp balls, wrap them in leaves and place them in a basket or bury them in the ground, to be used at times of food shortage. After several months, they retrieve the fermented balls and cook them by baking in hot ashes. The cassava pulp is boiled either by dropping the pie or balls into the boiling water or by stirring the pulp into water to form a sort of porridge. Porridge is sometimes made as a preliminary ste in the preparation of flour. The pulp is boiled and skimmed off with a plated spoon, strained through a mat of thin sticks and finally roasted in a pan to make flour.

Steaming and fermenting peujeum. A traditional product prepared in Java is peujeum (Stanton and Wallbridge, 1969). The peeled cassava roots are steamed until tender, allowed to cool and then dusted with finely powdered ragi, a rice flour starter culture flavoured with spices. The cassava mash mixed with ragi is wrapped in banana leaves in an earthenware pot and left for one or two days to ferment. The peujeum has a refreshing acidic and slightly alcoholic flavour and is either eaten immediately or baked.

Sun drying and pounding or grinding Into flour

Cassava roots, which may be soaked in water first, are sun dried and pounded into a noun This seems to be a general method everywhere.

In the preparation of fuku in Zaire the dried roots are pounded with partially fermented corn, the quantity depending on the season. The resulting flour is roasted on a Rat tray to stop further fermentation of the mixture, which was initiated by the fermenting maize. The flour is eaten as a gruel prepared in boiling water. Cassava flour is the basis of several other foods. In the preparation of nsua the flour is mixed with water and filtered through a jute bag. After removal of the water the paste is wrapped in a leaf and eaten raw. Ntinga is prepared in a similar way except that a portion of the paste is boiled in water and mixed with the remaining uncooked paste. The mixture is wrapped up in a leaf and cooked again.

Grating, pressing and roasting or baking to make flour or bread

These methods are widely used to prepare cassava flour or cassava bread in tropical America. Details vary from one group to another but the methods fall into two main groups depending on whether or not the roots are given a preliminary soaking:

***Unsoaked roots*. The process is very laborious and takes two or more days. The freshly dug roots are first washed to remove excess soil and then peeled. The tubers are then reduced to a pulp, normally by grating, but sometimes by crushing in a mortar or between stones. The pulp is squeezed with a variety of devices to expel the liquid. The moist pulp is left overnight in containers. Next day it is rubbed through a sieve to remove any coarse fibres. The pulp is then cooked in one of two ways depending on whether bread or flour is needed.**

***To prepare bread*, the cassava pulp is placed on a hot clay or stone griddle, pressed down into a thin layer and toasted on each side. The large, flat circular cakes are known as cassava bread, cassava casabe, beigu or couac depending on the locality. When fresh, the bread is soft inside and some people prefer to prepare it daily. More commonly, cassava bread is sun cried for several days during which time it hardens through. It can be stored in this form for several months. Cassava bread is normally eaten dipped into gruel or stew, which serves to soften it (Jones, 1959). Other types of bread can be made by adding additional ingredients to the cassava, for example in Brazil a special bread is prepared by adding pounded or grated Brazil nut to the cassava pulp.**

***To prepare flour*, the cassava pulp is stirred continuously while cooking on the griddle in order to prevent lumps forming. The resulting flour also stores well and is variously known as farinha de mandioca, farinha seca, farinha surruhy, kwak or koeak. It may be eaten dry, mixed with hot or cold water to make a paste or gruel or mixed with other foods. Various modifications and other**

methods, both simple and complex, are also used.

A traditional Philippine dish based on the cassava root is known as cassava rice or landang. Freshly dug roots are peeled and grated, the grated mass is put into jute sacks and pressed between two wooden blocks to squeeze out the juice. It is then put into a winnowing basket and whirled until pellets are formed. At intervals the pellets are sieved and those not passing through are put back and whirled again. The pellets are dried on a mat and then steamed in a coconut shell on a screen mesh placed over a vat of boiling water. The cooked pellets are placed in the winnowing basket and separated by hand. In an alternative process the peeled roots are submerged in fresh, clean water in an earthenware jar or wooden vessel for five to seven days until soft. They are then macerated, the fibres are removed and the remainder is dried and made into pellets as described. The pellets from both methods are dried thoroughly in the sun for three to five days and stored until needed. Cassava rice can be eaten without further cooking.

***Soaked roots*. In Latin America the cassava tubers, either peeled or unpeeled, are soaked in water usually for three to eight days but sometimes even longer IO allow some fermentation to occur. After removal from the water the peels are removed where necessary and the softened roots are either crushed by hand or grated to m eke a pulp and processed as for farinha seca. This method is also used to prepare cassava bread but more often the end product is cassava flour. Many variations of this basic process exist.**

In West Africa, after fermentation the cassava is pounded or ground to produce a paste which is consumed or stored depending on the country. In parts of Nigeria, the paste is boiled for 20 minutes and then removed for more pounding. In Cameroon, the wet paste is divided into two

portions and wrapped in leaves before cooking. In Mozambique cassava paste is mixed with flavouring ingredients including onion and salt, before being wrapped in leaves and boiled.

The preparation of pastes by pounding cassava is a peculiarly African process not practiced in South America. The pastes are consumed in a variety of forms, the best known being fufu. The term fufu and its variants are widely used in West Africa to refer to a sticky dough or porridge prepared from any pounded starchy root including yam, cocoyam and cassava.

In the preparation of fufu the roots are peeled, washed, grated and left to ferment for two to three days. To ferment the cassava the grated mass is either simply left to stand (Doku, 1969) or put into sacks and weighed with stones to squeeze out the juice. The resulting dough is used at once for cooking or it is stored in basins covered with cold water which is changed daily. The resulting product is consumed in different ways in different countries accompanied by stew or soup.

Gari the most popular cassava product consumed in Africa. To prepare gari cassava roots are washed, peeled and grated. The pulp is then placed in cloth bags or sacks made from jute and left to ferment, the fermentation time varying from three to six days. It is the fermentation process that gives gari its characteristic sour flavour, which distinguishes it from Brazilian farinha. During this stage pressure is applied to squeeze out the cassava juice. The cassava pulp, at about 50 percent water content, is taken out of the sacks and sieved to remove any fibrous material. It is then heated or "garified" in shallow pans and stirred continuously until it becomes light and crisp.

Gari is eaten in a variety of forms. It is sometimes eaten dry or made into a paste. More commonly

it is steeped in cold water, thus causing the particles to swell and soften but retaining their granular form. Alternatively, gari is mixed with cold water to make a thin gruel which is drunk with milk. A popular way of preparing gari in Nigeria is to soak it in boiling water to form a thick paste, eba, sometimes known as fufu.

Products essentially similar to gari are known by various names and are made throughout West Africa with minor variations to the processing. Recently gari processing has been mechanized in Nigeria.

A regional standard for Africa for gari was adopted by the Codex Alimentarius Commission (1986) which classified gari into five categories according to grain size and specified their essential composition and quality factors. These include raw material cassava and characteristic colour, taste and odour of gari and specification on acidity (not less than 0.6 percent nor more than 1 percent m/m determined as lactic acid). Total hydrocyanic acid (not exceeding 2 mg/kg determined as free HCN), moisture (not exceeding 12 percent m/m), crude fibre (not exceeding 2 percent m/m), ash content (not exceeding 2.75 percent m/m) and should be practically free from extraneous matter. Optionally edible fats or oils and salt may be added and gari may be enriched with added vitamins, proteins and other nutrients but addition of food additives was not allowed.

The methods used to process cassava in the South Pacific vary from island to island although boiling or baking the tubers are fairly widespread techniques. In the Solomon Islands the roots are often grated and mixed with coconut or banana as a pudding. In the New Hebrides, cassava is grated, wrapped in banana leaves and baked in an oven.

One method peculiar to the islanders in the South Pacific is the fermentation of tuber roots in pits, a process which prolongs the shelf-life of the product indefinitely. On the island of Mango in Tonga an abandoned pit estimated to be about 100 years old was found to contain food in an edible condition. Traditionally the pit is dug to a depth depending on the size of the family and lined with leaves of coconut, giant swamp taro or banana. The prepared food, which could be cassava, banana, taro or a mixture of all three, is placed in the pit to fill it and covered with more leaves, with rocks or logs placed on top to keep it in place. Fermentation proceeds for four to six weeks, after which the whole or part of the product is removed. Sometimes the fermentation is carried out with the addition of fresh water and sea water. In a modification of this process in Fiji, the unpeeled cassava root is fermented in a basked lowered into a lagoon. When it is required, it is removed, drained and pounded to a dough. The dough is kneaded with previously grated coconut, formed into balls, wrapped in breadfruit leaves and eaten either steamed or boiled. This product keeps for several months. If fresh water is used for the fermentation, the pulp is mixed with sugar or fruit, wrapped in leaves and steamed or boiled. This is known as bila and is a favourite food in Fiji. It keeps for several days.

Extraction of starch to prepare sipipa, tapioca and pot bammie

The juice obtained from grated cassava contains a certain amount of starch which settles out on standing for a few hours. In the Americas the liquid is decanted off, the starch residue is rinsed and then processed. It may be sun dried and eaten raw, or baked into crisp cakes called sipipa, which are highly prized as a delicacy by some groups. If it is still wet the starch is heated on a griddle when the starch grains burst and form granules known as tapioca flakes or globules. In Jamaica, starch is obtained by mixing grated cassava roots with water and straining the pulp

through a towel. The starch is allowed to settle out for a few hours. The water is decanted off and the starch is either dried briefly, then salted and baked into pot bammie, or dried for several days, pounded in a mortar, mixed with flour and cooked into dumplings.

In Asia the traditional methods of extracting starch are similar to those used in tropical America and Africa. The starch in the extracted cassava juice is washed and sun dried on a mat. Moist wet starch is used commercially to produce tapioca. To prepare tapioca the wet starch is gelatinized into globules and sun dried.

In the South Pacific starch is extracted from cassava roots by grating, washing and draining and is then dried in an oven to produce a granular, tapioca-like product.

In Padaids Island the pulp, from which the starch has been extracted, is also used. It is formed into balls of five to six cm in diameter and dried over a fire for about a week. When required for eating the dried cassava is grated again and mixed with coconut milk and water (Massal and Barrau, 1956).

In the Solomon Islands of Anuta and Tikopia, cassava is used to produce a fermented product called ma manioka on Anuta and masi manioka on Tikopia (Yen, 1978). On Tikopia, the cassava roots are soaked in water for five or more days until soft. They are then peeled, broken up, squeezed and ensiled in pits lined with leaves. On Anuta, where there is no suitable surface water, the roots are packed loosely in pits and left for a few weeks. They are then recovered, peeled and resumed to the same pits for a funkier period. Ma is used as an emergency food baked alone or in combination with freshly pounded starchy roots and fruits.

Processing cassava juice - cassava reep, beer

The cassava juice or yard, obtained by pressing the grated cassava, is commonly used to prepare sauces and beverages in South America and the West Indies. The yard is boiled down to a thick syrupy consistency. The soup is known as cassava reep in the West Indies. Groups inhabiting the area around the headwaters of the Amazon tributaries produce a refreshing sweet-tasting drink by boiling yard for several hours. An alcoholic drink may also be prepared by fermenting the cassava juice.

Preparation of beverages from cassava root

In addition to cassava juice, the whole root, the sliced, grated or pounded roots and cassava bread or flour are all used as starting materials for the preparation of beverages. Both non-alcoholic and alcoholic drinks are made.

***Non-alcoholic drinks*. The roots are peeled, grated, squeezed by hand and cooked. When cold they are masticated for a few minutes and allowed to stand for a short period but not long enough to produce an alcoholic drink. Similar drinks are made from cassava flour or bread.**

***Alcoholic drinks* . The preparation of cassava beers is widespread in tropical America. These are known as either kashiri or chicha. A number of different methods are used. The most common methods are the following:**

***Processing without mastication*. The drink is usually prepared by fermenting whole cassava roots.**

The tubers are left for up to a week in a stream for fermentation to occur. They are then removed and m ashed. Water is added to the mash which is left to stand for three days before drinking. Other methods of preparation are also used.

Many groups use cassava bread to prepare beverages. In Guyana freshly made cassava bread is dipped into water, placed in a shallow heap in a dark corner of the house and left, covered with leaves, for three to five days while moulds develop. The broken bread is then placed in large earthenware pots and left for a further two to five days. Finally water is added and fermentation takes place to produce a mildly intoxicating beverage. Other methods are used in Brazil and in Suriname to prepare alcoholic drinks from cassava bread.

***Processing with mastication*. The custom of mastication in the preparation of alcoholic drinks is common in tropical America. The majority of the traditional alcoholic drinks are prepared in this way. Mastication speeds up fermentation because the salivary enzymes initiate the conversion of starch to sugar.**

A variety of beverages is prepared from masticated cassava. In the Brazilian tropical forest, thinly sliced and boiled pieces of cassava are squeezed, chewed and left to ferment for one to three days. In the West Indies, a drink known as paiwari is prepared by this method. Other fruits, vegetables, maize and sweet potato may also be added as ingredients to the beer.

Beverage making from cassava is not generally practiced in Africa. Goode (1974) describes a method of preparation of beer in Uganda. The flour is mixed with water and left to ferment for a week. It is then roasted over a fire and put into a container to which water and yeast are added.

After about a week the liquid is drained, sugar is added and the beer is left to ferment for four days. Cassava flour is also used to make beer in South Africa, Southwest Zambia and Angola.

Cooking and processing of yam

By far the greater part of the world's yam crop is consumed fresh. Traditionally processed yam products are made in most yam-growing areas, usually as a way of utilizing tubers that are not fit for storage.

Usually fresh yam is peeled, boiled and pounded until a sticky elastic dough is produced. This is called pounded yam or yam fulu.

The only processed yam product traditionally made at village level is yam flour. Except by the Yoruba people in Nigeria, yam flour is regarded as an inferior substitute for freshly pounded yam because it is often made from damaged tubers. Yam flour is favoured in the Yoruba area where the reconstituted food is known as amala. To a limited extent, yam flour is also manufactured in Ghana where it is known as kokonte. The nutritional value of yam flour is the same as that of pounded yam.

Preparation of yam flour

The tubers are sliced to a thickness of about 10 mm, more or less, depending on the dryness of the weather. The slices are then parboiled and allowed to cool in the cooking water. The

parboiled slices are peeled and dried in the sun to reduce the moisture content.

The dried slices are then ground to flour in a wooden mortar and repeatedly sieved to produce a uniform texture. Today small hand-operated or enginedriven corn mills or flour mills are increasingly used.

Industrial processing

Yams have not been processed to any significant extent commercially. Dehydrated yam flours and yam flakes have been produced by sun drying. The manufacture of fried products from D. alata has also been attempted recently. Both chips and French fries have been manufactured. Preservation of yam in brine has been attempted, but with little success.

Since pounded yam has so much prestige and is the most popular way of eating yam, two attempts have been made to commercialize the process. The first was the production of dehydrated pounded yam by drum drying. This product could then be reconstituted without further processing. This production was first attempted in Cte d'Ivoire in the mid-1960s, under the trade name "Foutoupret", by air drying precooked, grated or mashed yam (Coursey, 1967). Onayemi and Potter (1974) used drum drying to produce a flake which can easily be reconstituted into pounded yarn by mixing with boiling water. This is the basis of the commercial product called "Poundo" in Nigeria, which was initially successful. To reduce wastage of raw material, peeling is done by using a 10 percent lye at 104C with varying immersion times depending on the cultivar of yam (Steele and Sammy, 1976). Sulphite is added to prevent enzymic browning.

In the second commercial project a type of food processor resembling a blender was developed. The yam is cooked, fumed and churned in a process equivalent to pounding, to give enough pounded yam for two to four servings. Both projects appeared at first to be very successful, but later people reverted to the manual pounding of yam which gives a characteristic viscosity and firmness that is difficult to simulate mechanically.

Attempts to manufacture fried yam chips, similar to French fried potatoes have been reported from Puerto Rico.

Cocoyam

Cocoyam is used in essentially the same way as yam. It can be eaten boiled, fried or pounded into fufu, although it is not considered as prestigious as yam. It has also been made info porridge or pottage, as well as chips and flour. Cocoyam flour has the added advantage that it is highly digestible and so is used for invalids and as an ingredient in baby foods.

Taro is the traditional staple in the Pacific Islands, where it is made into a series of food products similar to those described for cassava. Poi is a very popular Hawaiian and Polynesian dish made by pressure cooking the raw tuber, which is then peeled and mashed to a semi-fluid consistency. It is passed through a series of strainers, the final one having openings of about 0.5 mm diameter. It is then bagged and sold, or else stored at room temperature where it undergoes lactic acid fermentation. Coconut products can be added to the fermented poi before consumption.

In Nigeria cocoyam is grated, mixed with condiments and wrapped in leaves. It is steamed for about 30 minutes and served with sauce. Popularly known as ikokore, it is very common in the western Nigeria. A modification is available in Cameroon where cocoyam is made into balls and cooked with additional ingredients. This is known as epankoko.

Banana and plantain

One advantage of banana is that the dessert varieties can be eaten raw without any funkier processing. In many parts of Africa cooking banana is prepared by boiling or steaming, mashing, baking, drying or pounding to fufu. In Cameroon, green banana is boiled and served in a sauce of palm oil with fish, cooked meat, green beans, haricot beans and seasonings. In Uganda, where it is the staple, it is boiled with other ingredients including beans. Ghee is added together with pepper, salt and onions. This dish is called akatogo. Omuwumbo is prepared by wrapping the pulp in banana leaves and steaming it for about an hour. It is then pressed in the hands to a firm mass and eaten. The green form of banana is dried and stored. Known as mutere, it may be used for cooking after grinding into flour (Goode, 1974), but it is mainly used as a famine reserve. The same procedure is used in Gabon, in Cameroon, in South and Central America and in the West Indies (Fawcet, 1921).

A soup called sancocho is made in Colombia by boiling slices of green banana with cassava and other vegetables, while in the West Indies boiled green banana is served with salted fish or meat.

Mention has already been made of the fermentation of banana in pits in the Pacific. The

fermented product is formed into loaves and baked.

Known as mast, it keeps for over a year while buried in the pit, and baked masi stored in air-tight baskets in a deep hole may last for generations (Cox, 1980). The starch pseudo-stem and corm of the false banana, or ensete, is prepared by similar methods in Ethiopia. The fermented product, called kocho is used to prepare a flat, baked bread. Ripe bananas are preserved by sun drying. Known as banana figs, they are eaten as a sweetmeats. This product keeps for months or even years.

In West Africa bananas are parboiled before drying. Oven drying is practiced in Polynesia. The dried product is then bound tightly in leaves and stored until it is needed (Massal and Barrau, 1956). A similar technique is practiced in India.

In Burundi where banana occupies about 25 percent of the arable land, it is mainly used for the production of beer. It has been estimated that local beer is consumed at a rate of 1.21/caput/day. Making beer from banana is common in East Africa. Green banana is buried in pits covered with leaves to ripen for about a week, at which stage it also starts to ferment. The peels are removed, the pulp is mixed with grass in a trough and the juice is squeezed out. The residue is washed and added to the bulk of the juice. Roasted sorghum flour or millet is added and the mass is fermented for one to two days, covered with fresh banana leaves. In a modification of the process, honey is added to the fermented banana pulp.

Sweet potato

Sweet potato can also be eaten boiled, fried or roasted. When sliced, dried in the sun and ground, it gives a flour that remains in good condition for a long time. In Indonesia sweet potato is soaked in salt water for about an hour to inhibit microbial growth before drying. The flour is used as a dough conditioner in bread manufacturing and as a stabilizer in the ice-cream industry.

Sweet potato has been processed into chips (crisps) in much the same way as potato and the product is now popular in Asia. The sugar-coated chips are popular in China, the sailed variety is popular in the United States of America, while those spiced with cayenne pepper and citric acid have been tested in Bangladesh with favourable results (Kay, 1985).

Starch is produced from sweet potato in much the same way as from the other starchy roots except that the solution is kept alkaline (pH 8.6) by using lime, which helps to flocculate impurities and dissolve the pigments. The starch shows properties intermediate between potato starch and corn/ cassava starch in terms of viscosity and other characteristics. In Japan about 90 percent of the starch produced from sweet potato is used in the manufacture of starch syrup, glucose and isomerized glucose syrup, lactic acid beverages, bread and other food manufacturing industries.

In Japan, sweet potato starch is also used for the production of distilled spirits called shochu (Sakamoto and Bouwkamp, 1985). The process is very similar to that of whisky production except that the koji, equivalent to the malt starter in whisky production, is obtained by inoculating steamed rice soaked in water overnight with Aspergillus kawachii for two days at 35 to 37C. The koji is mixed with starch water and yeast to promote saccharification and fermentation. The filtrate is finally distilled. The yield is about 8001 from I tonne of sweet potato.

Potato

Like other root crops potato can be eaten boiled, fried or roasted. Since it is essentially a temperate root crop its use has been extensively commercialized. French fries and potato crisps are very popular snacks in the United States of America and else where. Unlike cereal starches the starch from potato sets rapidly at high temperatures and has a high hot-paste viscosity which makes it preferable for the manufacture of adhesives. It also finds applications in the textile industry, the food industry and in the production of alcohol and glucose. Most of these processes are mechanized and highly efficient. For short domestic storage, peeled potatoes are immersed in a solution of sodium metabisulphite to inhibit discolouration by enzymic action. They can then be refrigerated for several days before cooking and consumption.

The preparation of crisps is very similar to that of French fries except that the former are cut into very thin slices while the latter are cut into rods. The flour produced from potato is incorporated into bread, and is used as a thickener in dehydrated soups, gravies, sauces and baby foods. Dehydrated potato dice are ingredients in processed foods including canned meat, meat stew, frozen meat pies and salads.

Woolfe (1987) has given a detailed description of the processing of bitter potato in the Andes, especially of those varieties that contain toxic alkaloids. In the preparation of chuo blanco the potato is evenly spread on the ground on a very frosty night. If, on the following day it is not well frozen, it is exposed for another night. The successive freezing and thawing separates the tuber cells and destroys the differential permeability of the cell membrane, thereby allowing the cell sap to diffuse out from the cell into the intracellular spaces (Treadway et al., 1955). In this way by trampling the thawing tubers the liquid is squeezed out and the skins are removed. The residue is recovered and immersed in a running stream for one to three weeks, to remove toxins. After draining it is spread in the sun to dry. During the drying period a white crust forms on the tubers, which is the origin of the name of the food. Chuo blanco forms the basis of soup and stews. It is a delicacy among the inhabitants of the high Andean areas of Peru and Bolivia especially when served steaming hot with cheese.

The preparation of chuo negro is very similar to that of chuo blanco except that during trampling the skin is not removed, the soaking process is omitted, and the residue is simply sun dried after trampling. The product is dark brown-black in colour, and hence the name. It is usually soaked in water for one or two days before being cooked in order to remove any residual bitter flavours.

A more prestigious potato preparation that is popular in large cities and in Peru is papa seca. The potato is boiled, peeled, sliced and sun dried and then ground into a fine flour. The flour is normally used for a special dish called carapulca which is prepared with meat, tomato, onions and garlic, but it may also be made into soup.

These traditional techniques are particularly important for processing the bitter varieties of potato with a high alkaloid content, which would otherwise have been too toxic for food use. Christiansen (1977) found that the level of glycoalkaloids could be reduced, from 30 mg/100 g in the fresh potato, to about 4 mg in chuo blanco and 16 mg in chuo negro. In the Andean highlands, where frost, storm or drought can lead to destruction of crops, irregular yields and food shortages, it is essential to cultivate some frost-resistant bitter varieties of potato that can be

processed into reserve food from year to year.

A good review of simple technologies for root crop processing is provided by the United Nations Development Fund for Women publication, Root crop processing, 1989.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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6. Effect of processing on nutritional value

Contents - Previous - Next

Root crops are not easily digested in their natural state and should be cooked before they are eaten. Cooking improves their digestibility, promotes palatability and improves their keeping quality as well as making the roots safer to eat. The heat used during cooking can be dry heat as in baking in an oven or over an open fire, or wet heat as when boiling, steaming or frying. Heat helps to sterilize the food by killing harmful bacteria and other microorganisms, and it increases the availability of nutrients. Proteins are denatured by heat. In this form they are more easily digested by proteolytic enzymes; cellulosic cell walls that cannot be broken down by monogastric animals like man are broken down, and some anti-nutritional factors such as enzyme inhibitors are inactivated. However, processing may reduce the nutritional value of some root crops as a

result of losses and changes in major nutrients, including proteins, carbohydrates, minerals and vitamins.

Nutrients may be lost during cooking in two ways. First, by degradation, which can occur by destruction or by other chemical changes such as oxidation, and secondly by leaching into the cooking medium. Vitamins are susceptible to both processes while minerals are affected only by leaching. Free amino-acids could also be leached or may react with sugars to form complexes. Starches may be hydrolysed to sugars. The percentage loss will depend partly on the cooking temperature and on whether the food is prepared by boiling, baking or roasting. Baking losses may appear deceptively low if expressed on a fresh weight basis, due to the concentration of nutrients by loss of water. However, less damage is done by baking than by canning or drum drying (Purcell and Walter, 1982).

The first step in processing any root crop is usually peeling. This may remove nutrients if it is not done carefully. Cooking losses can be reduced by retaining the skin to minimize leaching and to protect the nutrients. It is sometimes advisable to peel after boiling, and to make use of the cooking water in order to conserve water-soluble nutrients.

Vitamin C is the most thermolabile vitamin and is also easily leached into cooking water or canning syrup. Elkins (1979) reported complete retention of vitamin C in freshly canned sweet potato but the vitamin content dropped to 60 percent of its original value after storage for 18 months. The concentration of the canning syrup did not affect vitamin retention (Arthur and McLemore, 1957). Air drying of thin slices of sweet potato leads to only slight losses of vitamin C.

Boiling may result in a 20 to 30 percent loss of vitamin C from unpeeled roots and tubers as shown in Table 6.1. If peeled before boiling the loss may be much higher, up to 40 percent. Swaminathan and Gangwar (1961) estimated that 10 to 21 percent of the loss is due to leaching into the cooking water and the rest to destruction by heat. Baking losses of vitamin C in unpeeled potato are about the same as in boiling but roasting results in higher losses, while making into crisps seems to be slightly better in terms of vitamin retention. Frying results in the loss of 50 to 56 percent compared to 20-28 percent on boiling unpeeled (RoyChoudhuri et al., 1963). Streghtoff et al. (1946) reported a 28 percent loss during baking and only a 13 percent loss when boiled after peeling. The difference may be that the higher temperature of baking leads to greater destruction of the vitamin. As much as 95 percent of the vitamin C is retained when yam is cooked with the skin on but this is reduced to 65 percent if it is cooked after peeling; 93 percent is retained on frying and 85 percent on roasting. (Coursey and Aidoo, 1966).

Up to 40 to 60 percent of the vitamin C content of potato can be lost on storage (Sweeny et al., 1969; Augustin et al., 1978; Faulks et al., 1982) depending on the temperature. Storage for 30 weeks at 5 or 10-C resulted in a loss of 72 percent and 78 percent respectively (Yamaguchi et al., 1960); and 49 percent loss at 8.5 months (Roine et al., 1955). On the other hand storing for 12 weeks at a tropical humid temperature of 16- or 28 C and 55 percent and 60 percent relative humidity, respectively, resulted in some sprouting and softening of the potato, followed by an increase in the vitamin C content from the initial value of 8.2 mg to 10.1 mg and 10.5 mg per 100 g respectively. This indicates that storage losses of vitamin C from potato are less in humid tropical conditions than in dry temperate conditions (Linnemann et al., 1985).

TABLE 6.1 - Composition of potato, cassava and plantain cooked by different methods (per 100 9)

TABLE 6.1 (cont.) - Composition of potato, cassava and plantain cooked by different methods (per 100 9)

Vitamin A is fat-soluble and thermo-stable so it will not normally be degraded by cooking. During studies on the canning of sweet potato, Arthur and MeLemore (1957) found no effect on the vitamin A content of the product due to syrup concentration, 0 to 35 percent sucrose, to cooking time, SO to 90 minutes, or to the peeling conditions. However, Elkins (1979) reported about 14 percent loss of vitamin A activity after processing sweet potato but no additional loss over 18 months, while other investigators have reported a 20 to 25 percent loss of vitamin A activity on cooking. This is probably because of the destruction of the beta-carotene. The main reaction that could take place during the canning of sweet potato is the isomerization of beta-carotene, to neobeta-carotene leading to a reduction in the vitamin A activity from 95 to 91 percent. The loss will be greater with increasing temperature (Panalaks and Murray, 1970). Losses of carotene and the development of off-flavours occur when sweet potato is stored at an ambient oxygen concentration at which antioxidants are not effective. About 20 to 40 percent of the carotene could be destroyed in the first 30 days from autoxidation. (Deobald and McLemore, 1964). At the same time autoxidation of the lipids, which are highly unsaturated, may occur leading to the development of the off-flavours.

Some of the reported losses in the B-group of vitamins are inconsistent because of differences in the heat lability of the vitamins. Thiamine is thermolabile, but boiling unpeeled potatoes reduced their thiamine content by only 23 percent, drying unpeeled potato led to a loss of only 20 percent while frying after peeling gave a 55 to 65 percent loss (Hentschel, 1969). Riboflavin and niacin are heat-stable and so there is complete retention of these nutrients on boiling, roasting or frying

potatoes, although some leaching losses may occur (Finglas and Faulks, 1985). The effect of cooking on the food value of boiled, steamed and baked taro (cocoyam) is shown in Table 6.2. In the ease of pyridoxine there is a 98 percent retention of this vitamin on boiling potatoes, the loss being higher with peeled than unpeeled potatoes (August in et al., 1978). However, no loss was reported on baking, roasting or frying, probably due to the concentration of nutrient through loss of water (Finglas and Faulks, 1985). Complete retention of thiamine and nicotinic acid in canned sweet potato has been reported, even after storage for 18 months (Elkins, 1979).

TABLE 6.2 - Effect cooking on composition of taro (cocoyam) (results calculated on fresh weight basis)

	Analysis of control (g /kg^{-1})		Differences		
			Boiled-control	Steamed-control	Baked-control
Moisture	655	(10.0)	44.0**	20.0*	-75.0**
Ash	7.6	(0.9)	-0.7*	0.1	0.5
Starch	278	(12.0)	32	29	11
Dietary five	12.2	(1.4)	8.2**	7.96**	7.7**
Sugars					
Fnuctose	1.0	(0.6)	-0.2	-0.1	-0.2
	0.6	(0.2)	-0.1	-0.1	-0.1

Glucose Sucrose	9 4	(1.6)	-0.8	-1.1	-1.3
Maltose	1.0	(0.3)	-0.2	-0.1	-0.1
Minerals mg/kg-1					
Ca	160	(30)	10	6.2	-9.0
P	330	(50)	11	41	45
Mg	320	(40)	-5.8	17	2.6
Na	34	(3.0)	9.3	9.5	-2.3
K	3 280	(360)	-410.0*	18	-60
S	54	(7 0)	-1 2	3 3	4
Zn	4.7	(0.5)	0.2	0.5	0.8
Mn	1.4	(0-5)	0.2*	0.2*	0.3
Al	3.1	(13)	0.9	1.1	-1.4*
B	0.9	(0-4)	-0.2	-0.1	-0.1

Results from five corms of cultivar Samoa were averaged. standard deviations in parentheses differences marked with one asterisk arc significant at P<0.05. those with two asterisks at P<0.01. Other results not included in the table are protein 9.6 (1.5), fat 0.5 (0.3), raffinose 0.3 (0.1) g/kg^{-1};

Fe 7.9 (1.8), Cu 2.0 (0.7) mg/kg^{-1}.
The value of 655 was the moisture content at harvest in Fiji, the moisture content before cooking in Canberra was 582 (17) g/kg-1.
Source: Bradbury & Holloway, 1988.

Storage has variable effects on different members of the vitamin B group. In potatoes stored at 5 or 10 C, 30 to 50 percent of their thiamine content is lost after six or seven months. There was a significant increase in pyridoxine level, 154 percent and 86 percent respectively for two varieties of potato kept for six months at 4.5C (Page and Hanning, 1963).

Raw potato starch is undigestible but digestibility increases with cooking time to 75 percent after 15 minutes and to 90 percent after 40 minutes (Hellendoorn et al., 1975). When the whole tuber is baked, as with sweet potato, virtually all the starch is hydrolysed to dextrin and sugars, mainly maltose. The concentration of reducing sugars is low, probably because of the Maillard reaction with lysine.

Baking may decrease the amount of pectin in roots and the degree of esterification, thereby decreasing their dietary fibre content, but this is not nutritionally significant.

The major change in amino-acids that occurs on cooking is the Maillard reaction which makes lysine unavailable, thereby reducing the nutritive value of the roots. Loss of free amino-acids also takes place through leaching (Meredith and Dull, 1979). When sweet potato was canned in 30 percent sucrose or water, the concentrations of essential amino-acids as a percentage of the original were 70 and 58 percent respectively, aromatic amino-acids 69 and 48 percent and sulphur

amino-acids 86 and 60 percent respectively. Purcell and Walter (1982) noted a significant reduction in the lysine and methionine content of sweet potato on canning, which may probably be due partly to leaching.

Boiling does not appreciably reduce the total nitrogen content of potato except for some loss owing to peeling. There is a 0.8 percent loss in the boiled, unpeeled tuber compared to a loss of 6.5 percent in the peeled tuber (Herrera, 1979). Nitrogen loss on roasting is also very small, apart from loss of lysine, with losses being greater in frying than baking.

Minerals are usually lost through being leached into syrup during canning, most especially with potassium, calcium and magnesium (Lopez et al. 1980); though the minerals can be completely retained if the tubers are vacuum-packed (Elkins, 1979). The iron content of canned sweet potato increased threefold after 18 months of storage and was obviously derived from the metal can. The leaching loss on boiling potatoes could be minimized if the skin were retained, as reported by True et al. (1979) who found over 90 percent retention when potato was boiled for 14 minutes with the skin on. There are no leaching losses in the case of copper and zinc and so they present no problem (Finglas and Faulks, 1985).

In some traditional processing an appreciable amount of protein could be lost. For example in the preparation of chuo blanco the protein content of the potato is reduced from 2.1 percent to 1.9 percent (Table 6.3). Some of the loss is because of removal in the exudate, but most of it takes place during the soaking in water, about 50 percent. Most of the vitamins are also lost in the process. There is a 90 percent loss in vitamin B1,75 percent in B2 and less than 50 percent of the niacin is retained. Papa seca, vitamins the best. There is an increase in the iron, calcium and

phosphorus content in all the preparations (Table 6.3) because of the increased concentration of the product.

In the preparation Of gari (Table 6.5) over one-third of the protein is lost, with greater losses for fufu and lafun (Oke, 1968). Most of the minerals are also reduced appreciably, except iron, which is increased, probably owing to the use of an iron pot for frying the product (Table 6.6). When yam is boiled, steamed or baked, the dietary fibre content rises because starch is modified and some minerals are lost, particularly phosphorus and potassium. (see Table 6.4.) Processing makes some difference to the percentage of nutrients that sweet potato will provide, as shown in Table 6.8. The 6.6 percent increase in the maltose content of sweet potato on cooking is not typical for other root crops, which presumably contain less amylases (Tamale and Bradbury, 1985).

TABLE 6.3 - Composition of raw potato, chuo and papa seca (per 1009)

Product	Energy		Crude protein (g)	Carbohydrate (g)	Ca (mg)	P (mg)	Fe (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic acid (mg)
	(kJ)	(Kcal)									
Raw potato	335	80	2.1	18.5	9	50	0.8	0.10	0.04	1.50	20
Chuo blanco	1 351	323	1.9	77.5	92	54	3.3	0.03	0.04	0.38	1.1
	1393	323	4.0	79.4	44	203	0.9	0.13	0.17	3.40	1.7

Chuo negro	1393	323	4.0	79.4	44	203	0.9	0.13	0.17	3.40	1.7
Papa seca	1347	322	8.2	72.6	47	200	4.5	0.19	0.09	5.00	3.2

Source: Woolfe, 1987.

TABLE 6.4 - Effect of cooking on composition of yam (results calculated on fresh weight basis)

	Analysis of control (g/kg^{-1})	**Differences**		
		Boiled-control	**Steamed-control**	**Baked-control**
Moisture	766 (12)	12.0*	-1.8	-68.0**
Ash	7.5 (0.3)	-1.2**	-0.1	0.1
Starch	186 (21)	5.8	-3.1	-3.6
Dietary fibre	15.6 (4.4)	16.3**	16.0**	9.2*
Sugars				
Fructose	2.2 (0.9)	-0.7	-0.6	-0.8
Glucose				
	1.6 (0.9)	-0.4	-0.5	-0.6

Sucrose	5.1 (2.4)	1.4	0.7	0.9
Maltose	0.8 (0.3)	0.1	-0.2	-0.2
Minerals mg/kg-1				
Ca	60 (12)	-2.6	-9.9*	-4.7
P	390 (20)	-33.0**	8.4	-25
Mg	150 (10)	-8.0	2.2	-11.4
Na	58 (25)	-28.0*	-17*	-8
K	3450 (200)	-630.0**	-70	-230
S	140 (10)	-17.0**	2.4	-1.0
Zn	3.2 (0.3)	0.1	-0.1	-0.3*
Mn	0.3 (0.1)	-0.1	-0.1	-0.1
Al	2.1 (1.1)	0	0.2	0.3
B	1.0 (0.1)	-0.2*	-0.1	-0.1

Results of five tubers of cultivar Da 10 were avenged standard deviations given in perentheses differences marked with one asterisk arc significant al P<0.05 those marked with two asterisks are significant at P<0.01. Other results not included above are protein 17.8 (3.9), fat 0.6 (0.5) raffinose

0.4 (0.3) g/kg^{-1}; Fe 6.5 (3.9) Cu 1.7 (0.3) mg/kg^{-1}.
The value of 766 was the moisture content at harvest in Western Samoa; the moisture content before cooking in Canberra was 752 (16) g/kg^{-1}.
Source: Bradbury & Holloway 1988

TABLE 6.5 - Proximate analysis of cassava and Its products (percentage of dry maker)

	Dry matter	Crude protein	Ether extract	Crude fibre	Carbohydrate	Ash	Calories
Cassava	28.5	2.6	0.46	0.43	94.1	2.4	391
Gad	85.6	0.9	0.10	0.40	81.8	1.4	323
Fufu	4.7	0.6	0.14	0.20	95.8	0.5	393
Lafun	80.5	0.8	0.40	0.73	96.4	2.0	391
Kpokpogarl	87.8	1.5	0.0	4.2	78.1	5.2	312

Source: Oke, 1968.

TABLE 6.6 - Minor elements In cassava and its products In Nigeria

Food stuff		
	Fraction in p.p.m. of dry matter	**Dry matter (percentage)**

	Na	Mn	Fe	Cu	B	Zn	Mo	Al	P	K	Ca	Mg
Cassava	56	12	18	8.4	3.3	24	0.9	19	0.15	1.38	0.13	0.04
Gari	74	12	22	4.3	6.6	19	0.7	30	0.04	0.52	0.07	0.00
Fufu	36	8	62	3.0	8.5	11	0.9	15	-	-	-	-
Lafun	54	12	66	5.0	9.5	19	1.0	125	-	-	-	-
Kpokpogari	74	1.0	12	3.0	3.3	19	1.0	165	-	-	-	-
Yam	22	8	8	8	9	17	0.9	15	0.09	1.5	0.16	0.05

Source: Oke, 1968

TABLE 6.7 - Effect of cooking on composition of sweet potato (fresh weight basis)

	Analysis of control g/kg^{-1}	**Difference**		
		Boiled-control	**Steamed-control**	**Baked-control**
Moisture	684 (29)	43.0	16.0**	-73.0**
Ash	7.6 (0-7)	-1.2**	-0.7*	0.4
Starch				
	213 (18)	-98.0**	-62.0**	-119.0**

Dietary fibre	14 (2.0)	20.6**	20.7**	11.2*
Sugars4				
Fructose	3.3 (12)	-0.8*	-0.4	-0.7*
Glucose	4.5 (11)	-0.6	-0.4	-0.8
Sucrose	20.3 (5.8)	1.1	1.9	4.0
Maltose	6.4 (10.2)	64.3**	68.8**	64.5**
Minerals mg/kg-1				
Ca	450 (60)	5	-67	-20
P	290 (30)	10	14	10.0*
Mg	360 (60)	28	-37	-6
Na	730 (160)	-127	-104	-27
K	2 430 (190)	-360	470.0*	370
S	130 (20)	1 1	11	8
Zn	2.9 (0.7)	-0.5**	0.1	0.6
Mn	2.6 (1.4)	0.1	-0.3	-0.1
Al	2.4 (1 2)	1.8	-1.0	-0.3

B	1.4 (0.2)	0.0	-0.1	-0.1

Other results are crude protein 17.7 (2.4) g/kg^{-1}, Fe 7.0 (2.6), Ca 2.2 (0.6) mg/kg^{-1}. Standard deviations given in paretheses.
Results of five tubers were averaged from three tubers of 83003-15, one tunber of each of 83003-13 and Hawaii. Differences showing one asterisk indicate a significant (P<0.05) change on cooking, two agterisks indicate P<0.01.
The value of 684 for moisture was that on harvesting in Tonga: the moisture content before cooking in Canberra was 634 (30) g/kg^{-1}.
[4]Total sugar: control 34.5, boiled 98.5, steamed 104.4, baked 101.5 g/kg^{-1}.
Source: Bradbury and Holloway, 1988.

TABLE 6.8 - Percentages of adult recommended daily allowances provided by 100 g servings of processed potato products

Potato product	Crude protein	Thiamin	Niacin	Folic acid	Pyridoxine	Ascorbic acid	Iron
Boiled in shin	6	8	8	7	11	50	7-12
Frozen, mashed reheated	5	5	4	-	-	13	7-12
French fries, finish-fried	8	8	11	6	18	40	11-20
	5	6	8	3	13	10	8-14

Chips4	5	6	8	5	15	19	8-14
Flakes (prepared)	5	0-3	5	-	-	17	3-6
Granules (prepared)	5	0-3	4	3	8	10	6-10
Canned (solids)	3	3	4	6	7	40	3-6

Unless otherwise indicated, calculated from figures for processed potato products given in Table 6.1 as percentages of RDAs given by Passmore et al. (1974).
As percentage of USA recommended daily allowance.
Domestic preparation.

[4]A 33.3 g serving, considered to be a more realistic estimate of a single serving of chips.
Source: Woolfe, 1987.

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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7. Toxic substances and antinutritional factors

Contents - Previous - Next

Root crops, in common with most plants, contain small amounts of potential toxins and

antinutritional factors such as trypsin inhibitors. Apart from cassava, which contains cyanogenic glucosides, cultivated varieties of most edible tubers and roots do not contain any serious toxins. Wild species may contain lethal levels of toxic principles and must be correctly processed before consumption. These wild species are useful reserves in times of famine or food scarcity. Local people are aware of the potential risks in their use and have developed suilable techniques for detoxifying the roots before consumption.

Cassava toxicity

The main toxic principle which occurs in varying amounts in all parts of the cassava plant is a chemical compound called linamarin (Nartey, 1981). It often coexists with its methyl homologue called methyl-linamarin or lotaustralin. Linamarin is a cyanogenic glycoside which is converted to toxic hydrocyanic acid or prussic acid when it comes into contact with linamarase, an enzyme that is released when the cells of cassava roots are ruptured. Otherwise linamarin is a rather stable compound which is not changed by boiling the cassava. If it is absorbed from the gut to the blood as the intact glycoside it is probably excreted unchanged in the urine without causing any harm to the organism (Philbrick, 1977). However, ingested linamarin can liberate cyanide in the gut during digestion.

Hydrocyanic acid or HCN is a volatile compound. It evaporates rapidly in the air at temperatures over 28 C and dissolves readily in water. It may easily be lost during transport, storage and analysis of specimens. The normal range of cyanogen content of cassava tubers falls between 15 and 400 mg HCN/kg fresh weight (Coursey, 1973). The concentration varies greatly between

varieties (Fig. 7.1) and also with environmental and cultural conditions. The concentration of the cyanogenic glycosides increases from the centre of the tuber outwards (Bruijn, 1973). Generally the cyanide content is substantially higher in the cassava peel. Bittemess is not necessarily a reliable indicator of cyanide content.

Traditional processing and cooking methods for cassava can, if efficiently carried out, reduce the cyanide content to non-toxic levels. An efficient processing method will release the enzyme linamarase by disintegrating the microstructure the cassava root. On bringing this enzyme into contact with linamarin the glucoside is converted into hydrogen cyanide. The liberated cyanide will dissolve in the water when fermentation is effected by prolonged soaking, and will evaporate when the fermented cassava is dried. Sun drying fresh cassava pieces for short periods is an inefficient detoxification process. Cyanide will not be completely liberated and the enzyme will be destroyed during drying. Sun drying processing techniques reduce only 60 to 70 percent of the total cyanide content in the first two months of preservation. Cyanide residues can be quite high in the dry tubers, from 30 to 100 mg/kg (Casadei, 1988). Simple boiling of fresh root pieces is not always reliable since the cyanide may be only partially liberated, and only part of the linamarin may be extracted in the cooking water. The reduction of cyanides depends on whether the product is placed in cold water (27C) or directly into boiling water (100C). After 30 minutes cooking, the remaining cyanides are, in the first case, 8 percent of the initial value, and in the second case about 30 percent (Easers, 1986).

Figure 7-1 - Effect of traditional processing of four varieties of cassava tuberous roots in the preparation of gari, on total and free cyanide content at each respective stage of processing

Various authors have suggested different minimal levels for toxicity. Rosling (1987) was of the opinion that an intake of over 20 mg per 100 g of cassava is toxic, while Bolhuis (1954) set the toxic level at an intake of 50 to 60 mg daily for a European adult.

Table 7.1 shows the HCN content of various processed cassava products. It indicates that a dramatic reduction in the hydrocyanic acid content of the raw cassava has occurred during processing. Soaking in water improves detoxification as cells are broken by osmosis and fermentation, which facilitates hydrolysis of the glycosides. Short soaking (four hours) is ineffective, but when longer periods are used (18 to 24 hours) cyanide levels can be reduced by 50 percent (Table 7.2). Squeezing the product is a fundamental step in the elimination of the soluble cyanides.

Pathophysiology of cyanide intoxication

Cyanide is detoxicated in the body by conversion to thiocyanate, a sulphurcontaining compound with goitrogenic properties. The conversion is catalysed by an enzyme thiosulphate cyanide sulphur transferase (rhodanase) present in most tissues in humans, and to a lesser extent by mercaptopyruvate cyanide sulphur transferase which is present in red blood cells (Fielder and Wood, 1956). The essential substrates for conversion of cyanide to thiocyanate are thiosulphate and 3-mercaptopyruvate, derived mainly from cysteine, cystine and methionine, the sulphur-containing aminoacids. Vitamin B12 in the form of hydroxycobalamin probably influences the conversion of cyanide to thiocyanate. Hydroxycobalamin has been reported to increase the urinary excretion of thiocyanate in experimental animals given small doses of cyanide (Wokes and Picard, 1955; Smith and Duckett, 1965). About 60 to 100 percent of the injected cyanide in toxic

concentration is converted to thiocyanate within 20 hours and enzymatic conversion accounts for more than 80 percent of cyanide detoxification (Wood and Cooley, 1956). Thiocyanate is widely distributed throughout body fluids including saliva, in which it can readily be detected. In normal health, a dynamic equilibrium between cyanide and thiocyanate is maintained. A low protein diet, particularly one which is deficient in sulphurcontaining amino-acids may decrease the detoxification capacity and thus make a person more vulnerable to the toxic effect of cyanide (Oke 1969, 1973). Excessive consumption of cassava, as the sole source of dietary energy and main source of protein, could thus increase vulnerability to cyanide toxicity.

TABLE 7.1 - HCN content of various cassava products during processing Remaining HCN

Food item	Detoxification stage	Remaining HCN	
		Mean (mg/kg)	(percentage)
Mpondu	Fresh leaves	68.6	100.0
	Washed leaves (cold waler)	63.9	93.1
	Dried leaves	66.1	96.3
	Boiled leaves (15 min in water)	3.7	5.4
	Boiled leaves (30 min in water)	1.2	1.7
	Boiled cassava		
	Fresh roots (sweet)	10.7	100.0
	Boiled roots (20 min In water)	1.3	12.1

Fufu	Fresh roots (sweet and bitter)	111.5	100.0
	Soaked roots (3 days)	19.4	17.4
	Dried roots (3 days)	15.7	14.1
	Uncooked fufu (flour and water)	2.5	2.2
	Cooked fufu	1.5	1.3
Fuku	Fresh roots (sweet)	25.5	100.0
	Uncooked fuku (heated)	4.2	16.4
	Cooked fuku	1.2	4.7
Gari	Mash	90.1	100.0
	24 h fermentation	73.2	81.2
	48 h fermentation	55.3	61.3
	48 h pressing	36.0	40.0
	Roasting	25.8	28.6
Lafun	Mash	16.5	100.0
	5 day soaking	35.9	21.8
	5-day soaking + 48 h drying	25.5	15.5

	5-day soaking + 96 h drying	19.6	11.9

Source: Bourdoux et al. 1982; Oke, 1984.

Diseases related to cassava toxicity

Several diseases have been associated with the toxic effects of cassava. Its causative role has been confirmed in the pathological condition of acute cyanide intoxication and in goitre. There is also some evidence linking two types of paralysis to the combined effects of a high cyanide and low sulphur intake, such as could result from a diet dominated by inefficiently processed cassava. In these two diseases, tropical atoxic neuropathy and epidemic spastic paraparesis, paralysis follows damage to the spinal cord. The role of cyanide toxicity in the causation of tropical diabetes, and in congenital malformation has not been established. Similarly its supposed beneficial effects on sickle cell anaemia, shistosomiasis and malignancies are still hypothetical.

***Acute cyanide intoxication*. Symptoms appear four to hours after after of raw or insufficiently processed cassava and consist of vertigo, vomiting, collapse and in some cases death within one or two hours. Treatment is quite effective and cheap. The principle is to increase the detoxicating capacity of the patient by giving an intravenous injection of thiosulphate and thereby making more sulphur available for conversion of cyanide to thiocyanate.**

***Endemic goitre*. Cyanide taken in the diet is detoxified in the body, resulting in the production of thiocyanate. Thiocyanate has the same molecular size as iodine and interferes with iodine uptake**

by the thyroid gland (Bourdoux et al., 1978). Under conditions of high ingestion of inefficiently processed cassava, there may be a chronic cyanide overload leading to a high level of serum thiocyanate of 1 to 3 mg/100 ml, compared to a normal level of about 0.2 mg/100 ml. Under such conditions there is an increased excretion of iodine and a reduced iodine uptake by the thyroid gland, resulting in a low thiocyanate/iodine (SCN/I) excretion ratio. The value of the threshold level for this ratio seems to be three (Derange et al., 1983) after which endemic goitre appears. This phenomenon can occur only when the iodine intake is below about 100 mg per day. At SCN/I ratios of lower than two there is a risk of endemic cretinism, a condition characterized by severe mental retardation and severe neurologic abnormalities (Ermans et al., 1983).

Studies in Zaire have shown that the population of Ubangi, who consume a high amount of sun dried but unfermented cassava products, have a low SCN/I ratio of 2 to 4 and suffer from endemic goitre and cretinism. Whereas in Kim, where fermented and dried cassava paste is eaten, the SCN/I ratio goes up to three to five and there is a low incidence of goitre. In Bas Zaire, where properly processed cassava products are eaten, the SCN/I ratio is higher than seven and there is no goitre. A low ratio leads to abnormal levels of the thyroid stimulating hormone (TSH) and low thyroxine (T4). Ayangade et al., (1982) found that in pregnant women the thiocyanate level of the cord blood was proportional to the maternal serum thiocyanate level, indicating that thiocyanate can cross the placental barrier and affect the foetus. However, there is very little thiocyanate in breast milk indicating that the mammary gland does not concentrate thiocyanate and so breast-fed infants are not affected.

When iodine supplements are given, for example, by adding potassium iodide to local supplies of salt, goitre is reduced in spite of a continued high intake of cassava products. Where salt intake is

small or variable, iodized oil, given by mouth, provides protection for one to two years. In the Amazon jungle some tribal people eat as much as one kg of cooked fresh cassava per person per day and consume up to three litres of fermented cassava beer, but there have been no reported eases of either goitre or ataxic neuropathy. These tribes also consume a considerable amount of animal and fish protein and thus have high levels of sulphur-amino acids and iodine in their diet.

Neurological disorders

Cyanide intake from a cassava-dominated diet has been proposed as a contributing factor in two forms of nutritional neuropathies, tropical ataxic neuropathy in Nigeria (Osuntokun, 1981) and epidemic spastic paraparesis (Cliff et al., 1984). These disorders are also found in some cassava growingareas of Tanzania and Zaire.

***Tropical ataxic neuropathy*. This disease is common in a particular area in Nigeria where a lot of cassava is consumed without the addition of sufficient protein-rich supplementary foods to provide an adequate supply of sulphur amino-acids for the detoxification of ingested cyanide. The consumed cassava product, called purupuru, is processed by an insufficient fermentation of the cassava, which leaves a residual cyanide content of up to 0.10 M mole/g. As much as two kg of this foodstuff is consumed daily, leading to the ingestion of about 50 mg of cyanide. The toxic level for an adult is about 60 ma. The clinical picture is dominated by damage to one of the sensory tracts in the spinal cord resulting in an uncoordinated gait called ataxia.**

When patients are brought to the hospital they have a high plasma thiocyanate level. On admission they are put on a hospital diet which is highly nutritious and includes cassava only

twice a week. Within a short period the plasma thiocyanate level returns to normal, and the patients recover. However, on discharge, they go back to their original diet of cassava and so the condition reappears (Osuntokun, 1968).

All the cases reported came from the area where cassava is cultivated and eaten in large quantities, with no cases in the nearby areas where yam predominates. A change in the diet of the population at risk in Nigeria has reduced the incidence of this disease.

***Epidemic spastic paraparesis*. This is a situation of depending on very toxic varieties of cassava as a food security crop (Cliff et al., 1984). In parts of Mozambique a bitter toxic type of cassava is often planted as a food reserve because of its high yield. As cassava constitutes about 80 percent of the basic diet, there is nominally a standard method of preparation which makes the cassava safe for consumption. Cassava, containing about 327 mg HCN/ kg, is peeled, sliced and sun dried for about three weeks after which the cyanide level is reduced to about 95 mg/kg. It is then pounded to a flour which is mixed with hot water to make a paste called chima. This paste is normally eaten with a relish of beans, fish or vegetables, to provide a well balanced meal.**

During a prolonged period of drought all the food crops in this area were lost except the toxic variety of cassava. The foodstores were depleted and many families had no alternative, but to resort to the toxic cassava. Normal processing time was reduced because of the emergency and so there was no proper detoxification. The people knew this but they had no other choice of action except to die of starvation. On eating the underprocessed chima without their usual protein-rich supplement they complained that it was more bitter than normal. After about four to six hours they suffered from nausea, vertigo and confusion. Sufferers showed a high serum thiocyanate

level and a urinary thiocyanate excretion of about ten times that of non-cassava-eating groups in Mozambique. There followed a sudden appearance of many cases of spastic paraparesis, indicating an extensive epidemic. This disease affects mainly women and children. It damages the nerve tract in the spinal cord that transmits signals for movement, thus causing a spastic paralysis of both legs (Rolling, 1983). Outbreaks have been reported during the dry season from two areas in Zaire (Nkamany and Kayinge, 1982) and during droughts in one area in Mozambique (Cliff et al., 1984) and one area in Tanzania (Howlett, 1985).

During these drought periods about 500 g of dried cassava, or 1.5 kg on a fresh weight basis, is consumed daily, representing an intake of 1 500 kcal and 50 mg cyanide per day. This level approaches the toxic level of 60 ma. The body can safely detoxify about 20 mg cyanide per day but when this level increases to 30 mg symptoms of acute intoxication develop in many consumers and hence the epidemics. If there is a period during which a high cassava intake and a low protein-rich food intake, to supply sulphur amino-acids for detoxification, coincide, this combination precipitates the outbreak of this disease. The situation may be compared to the epidemics of lathyrism that occured in drought-affected areas of India owing to the high-level intake of the drought-resistant pea, Lathyrus saliva.

Production of low-cyanide foods

The development of a more sensitive method for cyanide determination in foods by Cooke (1978a) and an in-depth study of some traditional cassava foods have led to a better understanding of the detoxification mechanism of cyanide in foods and to improved recommendations for processing cassava.

Cyanide occurs in cassava and cassava products in two forms, the glucosidic form, which is the linamarin itself, and the non-glucosidic or bound form which is cyanohydrin. Under normal conditions of hydrolysis, when the enzyme linamarase reacts with linamarin, it is hydrolysed to cyanohydrin which, on decomposition, gives acetone and hydrocyanic acid. However, under acid conditions, of pH4 or less, which tend to occur in some lactic acid fermentations of cassava, the cyanohydrin decomposition is hindered and it becomes stable. It is relatively easy to get rid of free cyanide, which is present at about 10 percent in both peeled and fresh cassava, especially in solution, but the non-glucosidic cyanide may hydrolyse very slowly and result in a lot of residual cyanide in cassava products. Thus drying cassava chips in an air oven at 47 and 60C causes a decrease in the bound cyanide content of 25 to 30 percent, whereas faster drying at 80C or 100C gave only a 10 to 15 percent decrease of the bound cyanide. However, losses of free cyanide were 80 to 85 percent and 95 percent respectively (Cooke and Maduagwu, 1978b). Drying results in an apparent increase in cyanide concentration because of loss of water (Bourdoux et al., 1982). The longer the drying the higher the amount of water removed. About 14 percent of the water can be removed during the first day, reaching a level of up to 70 percent after eight days. This leads to an increase in cyanide concentration from 70 mg/kg on the first day to 91 mg/kg after eight days.

Soaking in water at 30C, boiling or cooking removes free cyanide but only about 55 percent of the bound cyanide is released after 25 minutes. However, the bound cyanide is removed by prolonged soaking as fermentation begins (Table 7.2) through the action of the enzyme linamarase which is released by disruption of the tuberous tissues. If water is added at this stage most of the cyanide is removed. Meuser and Smolnik (1980) were able to improve the production of gari by washing the mash after fermentation to remove the residual bound cyanide which was still present as

cyanohydrin because of its higher stability at the lower pH.

The result of different drying techniques is shown in Table 7.3. Freeze drying or rash-drying eliminated only the free cyanide, which accounted for about 50 percent of the total cyanide present. Roller-drying of the fresh pulp at a pH of 5.5 to 5.7 removed virtually all the cyanide, whereas if the fermented pulp was dried on rollers or on drums high amounts of cyanide were retained in the dried product because of the acid condition (pH 3.8) of the fermented pulp. In the detoxification of cassava products fermentation is most effective when accompanied by squeezing and washing of the acidic pulp. Residual cyanide can be reduced further by sun drying or frying. This had been confirmed by Hahn (1983) as shown in Fig. 7.1. In traditional preparations of various food products from cassava, there may be some residual cyanide because of insufficient tissue disintegration during processing and insufficient washing. It is the residual cyanide that is responsible for toxicity. Some of these preparations have been simulated in the laboratory and modified to give much lower cyanide levels (Bourdoux et al., 1983).

TABLE 7.2 - Effects of soaking on the HCN content of six bitter cassava roots

Soaking period (days)	Remaining HCN (percentage)
0	100.0
1	55.0
2	42.3
3	19.0

3	19.0
4	10.9
5	2.7

Source: Bourdoux et al., 1983

Sweet potato

Sweet potato contains raffinose, one of the sugars responsible for flatulence. Three of the sugars which occur in plant tissues, raffinose, stachyose and verbascose are not digested in the upper digestive tract, and so are fermented by colon bacteria to yield the flatus gases, hydrogen and carbon dioxide. The level of raffinose present depends on the cultivar. In some parts of Africa the cultivars used are considered too sweet and cause flatulence (Palmer, 1982), Lin et al. (1985) have established that sweet potato shows trypsin inhibitor activity (TIA) ranging from 90 percent inhibition in some varieties to 20 percent in others. There is a significant correlation between the trypsin inhibitor content and the protein content of the sweet potato variety. Heating to 90C for several minutes inactivates trypsin inhibitors. Lawrence and Walker (1976) have implicated TIA in sweet potato as a contributory factor in the disease enteritis necroticans. This seems doubtful since sweet potato is not usually eaten raw and the activity of the trypsin inhibitor present is destroyed by heat.

In response to injury, or exposure to infectious agents, in reaction to physiological stimulation or

on exposure of wounded tissue to fungal contamination, sweet potato will produce certain metabolites. Some of these compounds, especially the furano-terpenoids are known to be toxic (Uritani, 1967). Fungal contamination of sweet potato tubers by Ceratocystis fimbriata and several Fusarium species leads to the production of ipomeamarone, a hepatoxin, while other metabolites like 4-ipomeanol are pulmonary toxins. Baking destroys only 40 percent of these toxins. Catalano et al. (1977) reported that peeling blemished or diseased sweet potatoes from 3 to 10 mm beyond the infested area is sufficient to remove most of the toxin.

TABLE 7.3 - Effect of drying on HCN consent of cassava

Drying process		**HCN (ppm)**
Freeze drying	Pulp	439
Flash drying	Slices	432
Air drying 40C	Chips. pulp	13
Heated air drying 180C	Chips	14
	Fermented pulp	77
Drum drying	Pulp	8
	Fermented pulp	121
HCN of pulp	free and bound	900

Source: Meuser & Smolnik, 1980.

Potato

Potato contains the glycoalkaloids alpha-solanine and alpha-chaconine (Maya, 1980), concentrated mainly in the flowers and sprouts (200 to 500 mg/100 g). In healthy potato tubers the concentration of the glycoalkaloids is usually less than 10 mg/100 g and this can normally be reduced by peeling (Wood and Young, 1974; Bushway et al., 1983). In bitter varieties the alkaloid concentration can go up to 80 mg/100 g in the tuber as a whole and up to 150220 mg/100 g in the peel. The presence of these glycoalkaloids is not perceptible to the taste buds until they reach a concentration of 20 ma/100 g when they taste bitter. At higher concentrations they cause a burning and persistent irritation similar to hot pepper. At these concentrations solanine and other potato glycoalkaloids are toxic. They are not destroyed during normal cooking because the decomposition temperature of solanine is about 243 C.

Levels of glycoalkaloids may build up in potatoes which are exposed to bright light for long periods. They may also result from wounding during harvest or during post-harvest handling and storage, especially at temperatures below 10C (Jadhav and Salunkhe, 1975). Glycoalkaloids are inhibitors of choline esterase and cause haemorrhagic damage to the gastrointestinal tract as well as to the retina (Ahmed, 1982). Solanine poisoning has been known to cause severe illness but it is rarely fatal (Jadhav and Salunkhe, 1975).

Potato also contains proteinase inhibitors which act as an effective defense against insects and micro-organisms but are no problem to humans because they are destroyed by heat. Lectins or haemogglutenins are also present in potato. These toxins are capable of agglutinating the

erythocytes of several mammalian species including humans (Goldstein and Hayes, 1978), but this is of minimal nutritional significance as haemogglutenins are also destroyed by heat, and potatoes are normally cooked before they are eaten.

Cocoyam

The high content of calcium oxalate crystals, about 780 mg per 100 g in some species of cocoyam, Colocasia and Xanthosoma, has been implicated in the acridity or irritation caused by cocoyam. Oxalate also tends to precipitate calcium and makes it unavailable for use by the body. Oke (1967) has given an extensive review of the role of oxalate in nutrition including the possibility of oxalaurea and kidney stones. The acridity of high oxalate cultivars of cocoyam can be reduced by peeling, grating, soaking and fermenting during processing.

Acridity can also be caused by proteolytic enzymes as in snake venoms. Attempts have been made to isolate such enzymes from taro, Colocasia esculenta, and the principal component has been called "taroin" by Pena et al. (1984).

Banana and plantain

Banana and plantain do not contain significant levels of any toxic principles. They do contain high levels of serotonin, dopamine and other biogenic amines. Dopamine is responsible for the enzymic browning of sliced banana. Serotonin intake at high levels from plantain has been implicated in the aetiology of endomyocardial fibrosis (EMF) (Foy and Parratt, 1960). However, Ojo

(1969) has shown that serotonine is rapidly removed from the circulating plasma and so does not contribute to elevated levels of biogenic amines in healthy Nigerians. It has been confirmed by Shaper (1967) that there is insufficient evidence for regarding its level in plantain as a factor in the aetiology of EMF.

Yam

The edible, mature, cultivated yam does not contain any toxic principles. However, bitter principles tend to accumulate in immature tuber tissues of Dioscorea rotundata and D. cayenensis. They may be polyphenols or tanninlike compounds (Coursey, 1983). Wild forms of D. dumetorum do contain bitter principles, and hence are referred to as bitter yam. Bitter yams are not normally eaten except at times of food scarcity. They are usually detoxified by soaking in a vessel of salt water, in cold or hot fresh water or in a stream. The bitter principle has been identified as the alkaloid dihydrodioscorine, while that of the Malayan species, D. hispida, is dioscorine (Bevan and Hirst, 1958). These are water soluble alkaloids which, on ingestion, produce severe and distressing symptoms (Coursey, 1967). Severe cases of alkaloid intoxication may prove fatal. There is no report of alkaloids in cultivated varieties of D. dumetorum.

Dioscorea bulbifera is called the aerial or potato yam and is believed to have originated in an Indo-Malayan centre. In Asia detoxification methods, involving water extraction, fermentation and roasting of the grated tuber are used for bitter cultivars of this yam. The bitter principles of D. bulbifera include a 3furanoside norditerpene called diosbulbin. These substances are toxic, causing paralysis. Extracts are sometimes used in fishing to immobolize the fish and thus facilitate

capture. Toxicity may also be due to saponins in the extract. Zulus use this yam as bait for monkeys and hunters in Malaysia use it to poison tigers. In Indonesia an extract of D. bulbifera is used in the preparation of arrow poison (Coursey, 1967).

Contents - Previous - Next

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

Phytate

Contents - Previous - Next

Phytate is a storage form of phosphorus which is found in plant seeds and in many roots and tubers (Dipak and Mukherjee, 1986). Phytic acid has the potential to bind calcium, zinc, iron and other minerals, thereby reducing their availability in the body (Davis and Olpin, 1979; O'Dell and Savage, 1960). In addition, complex formation of physic acid with proteins may inhibit the enzymatic digestion of the protein (Singh and Krikorian, 1982). Iron and zinc deficiencies occur in populations that subsist on unleavened whole grain bread and rely on it as a primary source of these minerals. Deficiencies have been attributed to the presence of phytates.

Recently Marfo and Oke (1988) have shown that cassava, cocoyam and yam contain 624 ma, 855 mg and 637 mg of phytate per 100 g respectively (Table 7.4). Fermentation reduced the phytate

level by 88 percent, 98 percent and 68 percent respectively, reduction being rapid within 48 hours but very slow after 72 hours processing. Thus processing into fermented foods will reduce the phylate level of root crops sufficiently to nullify its adverse effect. The loss of phytate during fermentation is due to the enzyme phytase, naturally present in the tubers or secreted by fermentative microorganisms. Processing into nbo or kokonte resulted in a loss of only 18 percent of phytate in cassava and 30 percent each in cocoyam and yam (Table 7.5). Oven-drying has only a small reductive effect on the phytate content compared with fermentation. Cooking also has a significant effect, resulting in decrease of phytate of 62 percent, 65 percent and 68 percent respectively in yam, cocoyam and cassava.

TABLE 7.4 - Phytate content of some unfermented and fermented tubers (mg/g)

Sample	Unfermented meal	Fermented mean.				Percentage
		(24 h)	(48 h)	(72 h)	(96 h)	lose
Cassava	624	116	99	90	70	88.7
Cocoyam	855	180	28	13	13	98.4
Yam	637	394	296	222	211	66.8

Percentage loss in phytate is the decrease in phytate after 96 hours fermentation expressed as a percentage of total phytate.
Source: Marfo & Oke, 1988.

TABLE 7.5 - Effect of processing on phytate In cassava, cocoyam and yam

	Fresh and unprocessed	Sliced and cooked (Ampesi)	Flour cooked into a paste (Tug, kokonte)	Dried granular powder (Gari)	Gari made into a paste (Eba)	Fufu (cooked and pounded)
CASSAVA	624	196	411	70	55	188
percentage loss	-	68.5	18.1	86.0	89.0	69.8
COCOYAM	855	302	592	9	8	281
percentage loss	-	64.6	30.7	98.9	99.0	67.1
YAM	637	239	412	188	179	209
percentage loss	-	62.4	30.8	70.4	71.8	67.1

Percentage loss in phytate is the decrease in phytate resulting from each processing method expressed as a percentage of total phytate content.
Source: Marfo & Oke, 1988.

8. New frontiers for tropical root crops and tubers

In this chapter agro-industrial possibilities for the expanded utilization of root crops are reviewed. The success of efforts made to increase the production of tropical root crops and to promote their use as food will depend on market demand. Farmers will not be encouraged to produce a marketable excess if this leads to glut, spoilage, and low prices. Policy makers should not only promote policies to increase consumption of root crops as human foods and as animal feeds, but should also support research that will extend the utilization of these root crops. Efforts should be made to promote new technologies, appropriate for use by the rural population, to produce a variety of processed foods from root crops. This strategy will generate employment and improve incomes in rural areas. If demand is stimulated farmers will be encouraged to produce more root crops which can be converted to animal feed and industrial uses. Demand can be stimulated by development in three main areas:

- **commercial dehydration of the root crops to produce flakes and flour that can be made into other food products;**
- **use of root crops as sources of industrial raw materials; and**
- **use of root crops as animal feed.**

Commercial dehydration of root crops and their use

The peeled root is rinsed to remove excess starch, then cut into slices, blanched, blended to a

puree and dried. Peeling can be effected by immersion in 10 percent lye solution or by steaming at high temperatures (150C) for short periods.

The drier, which may be a heat exchanger or drum drier, can be fired by agricultural wastes such as coconut husks which are abundant and cheap in Southeast Asia. This reduces the moisture content from 70 percent to 12 percent. Improved preservation of root crops would increase their availability and reduce post-harvest wastage. Dried products require less storage space and have a longer shelf-life. They can be quickly reconstituted and prepared for eating, a factor of particular importance to urban consumers. Composite flour incorporating cocoyam has been used in extruded products such as noodles and macaroni. Similar processes could be used in the production of flour products from other root crops.

Processing will greatly increase the utilization of root crops. The flour can be used as a component of multimix baby foods and in composite flour for making bread. Research and development work on composite flour using root crops and other local products has advanced considerably in Colombia. Based on initial research in 1971-72, it was concluded that while rice and maize flours are preferable for use as non-wheat components in composite flours, cassava flour and starch also have good technical possibilities. The pilot work demonstrated that the production of bread from wheat flour diluted up to 30 percent with non-wheat components is possible on a commercial scale. But the large-scale introduction of such flours requires a concerted effort by both the public and private sectors to ensure the wide-spread availability at attractive prices of non-wheat raw materials. Expanded cassava production and lower prices are required if composite flour is to be economically attractive to millers and consumers (Goering, 1979).

Bread baked with composite flour from local resources would reduce the foreign exchange cost of imported wheat. This cost is particularly high in the Philippines, where a processing plant has been set up to convert 5 000 kg of fresh sweet potato into flour every day. The bread from this flour will contain more calories and a higher content of vitamin A and lysine than wheat bread and will conserve foreign exchange. If it can be marketed at a reduced cost it may help to improve the nutritional status of the population. Taylor (1982) estimated that cash benefits to farmers producing raw material for this plant could substantially improve with a guaranteed market. Since the market and the financing of the crop is guaranteed, the promotion of sweet potato as a cash crop will be more easily accepted.

Fresh root crops are rarely exported in appreciable quantities because of their high water content and perishability. Cocoyam is exported in small amounts from Fiji, Western Samoa, Tonga and Cooke Island to the United States of America, New Zealand and Australia for the Polynesian and Melanesian immigrants. Yams are also exported from Latin America and Africa for immigrants in Europe, but quantities are small and prices are high.

Use of root crops as a source of industrial raw material

Most of the world's starch supplies are derived from either grains (corn, sorghum, wheat, rice), the major root crops (potato, sweet potato, cassava, arrowroot) or the pith of the sago palm. While starches from these various plant sources vary slightly in their physical and chemical properties, they can be substituted for each other across a wide spectrum of end uses. Cassava starch must compete with other starches and relative prices, quality and dependability of supplies

are basic considerations in the determination of market shares (Goering, 1979).

Cassava tubers can be processed as a source of commercial starch for use in the foodstuff, textile and paper industries. As a foodstuff the starch may be converted by acid and enzyme hydrolysis to dextrins and glucose syrups, but maize starch is often available at a lower price for these purposes. The bland flavour of cassava starch, its low amylose content, non-retrogration tendency and excellent freeze-thaw stability makes it suitable for use in food processing. Simple modification of Cassava starch by cross-bonding, or use of maize starch/cassava blends give properties ideally suited for use in a wide range of convenience foods. Starch from cocoyam has been recommended as a diluent in chemical and drug manufacturing and as a carrier in cosmetics such as face powder. It has a grain size similar to rice starch which is currently used for these purposes.

Cassava starch is manufactured in Thailand, Brazil and Malaysia and exported mainly to Japan and the United States of America. In 1975 the export level had reached about 100 000 tonnes per annum, equivalent in value to about US$30 million, with Thailand controlling about 50 percent of the market. In Thailand starch mills of various sizes have been set up including about 60 small mills with a unit capacity of two to three tonnes of starch per day, a similar number of modem mills producing 30 to 60 tonnes per day and a few industrial mills with a capacity of 100 to 150 tonnes per day. All these mills combine to give a total annual production of about 800 000 tonnes, of which about 700 000 tonnes are produced in modem mills. In Thailand a high proportion of the cassava starch produced can be utilized by local industries while the remainder is exported to other countries that have textile industries.

In several countries the traditional starch industry is an important source of starch for local users and provides a readily accessible market for tropical root crop production from small-scale farmers. A significant amount of rural nonfarm employment also is generated by the industry. Factories typically are small scale (one tonne of raw root throughput per hour), are equipped with locally fabricated machinery and use crude sedimentation processes which result in a product of variable quality. This local industry frequently finds it difficult to compete with large-scale, semi-automated factories (throughput of up to 20 tonnes per hour) or with factories using grain, sometimes imported at low prices, as the raw material. Since the price of cassava roots is normally governed by the pellet industry, only limited possibilities exist to reduce starch prices in order to make exports more competitive. The excess capacity in the Thai starch industry places that country in a good position to meet the requirements of any future new markets elsewhere. The possible export of root starches is less attractive for other developing countries that do not have established positions in the market (Goering, 1979).

Starch can be hydrolysed to glucose and used as a sweetener. Starches from root crops are often more expensive than those obtained from cereals such as rice and maize. Increased production could possibly reduce root starch costs and make it more competitive. Fig. 8.1 presents a diagram of a potential agroindustrial system for cassava utilisation.

Yeast fermentation of the hydrolysed starch extract of cassava or other crops gives a good yield of absolute ethyl alcohol, which can be used as an extender of petroleum-based fuels by blending up to 20 percent, without altering the carburettor of most petrol engines. Brazil initiated a National Alcohol Programme in 1975 to produce ethyl alcohol from agricultural raw materials, much of it based on sugar cane. The technology is now well developed and production has started. The

starch-to-alcohol conversion ratio is 1.76 kg starch for one litre of alcohol. Sugar cane is the most energy efficient crop for alcohol production, but the use of cassava starch is increasing because it can be produced under conditions unsuitable for sugar cane. The cost from cassava was estimated at $0.57/gallon in 1978. PETROBRAS of Brazil was the first to test a large-scale plant to produce alcohol from cassava, with a full production capacity of 60 000 litres per day. Early runs were hampered by inadequate supplies of raw material and the high prices of cassava roots compared to the government-controlled price of petrol. During test runs 30 000 litres of alcohol were produced to specifications. Doubling cassava yield would make the process more economical. This could lead to an increased production of cassava and its use as a renewable energy resource (Hammond, 1977).

Figure 8-1 - An agro-industrial system for cassava

Plans are under consideration in Indonesia to develop a number of commercial alcohol factories using raw material from sweet potato, cassava and sugar cane. Special attention will be given to sweet potato production because it can be harvested twice in a year compared to cassava which is harvested only once a year (Yang, 1982). Guaranteed markets are a great incentive to farmers to produce more root crops.

Fermentation of commercial starches with Clostridium acetobutylicum yields about 30 percent of the starch dry weight of mixed solvents of butanol, acetone and ethyl alcohol, from which the pure products can be obtained by distillation. A process based on high-yielding cassava cultivars as a starch source could be financially attractive.

Some root crops have considerable pharmaceutical potential not yet exploited in developing countries. Yam contains steroidal sapogenins which are useful starting materials for the preparation of cortisone and related drugs. In Mexico various wild species of Dioscorea, especially D. mexicana, contain useful quantities of these sapogenins as high percentage of the dry matter, end they can be converted into progesterone intermediates. Other species are good sources of diosgenin, a starting material for the manufacture of corticosteroids. Oral contraceptives based on progesterone are now widely used in family planning in several tropical countries. The possibility exists for their national production from local materials. This prospect has been extensively reviewed by Oke (1972).

Some species of Dioscorea grown in Southeast Asia contain toxic saponins. They are made locally into a medicinal shampoo which is used to destroy head lice. They are also used in an insecticidal powder, similar in effect to derris dust, which is used to destroy rice parasites in paddy fields in Malaysia. D. cirrhosa contains enough tannin for commercial use. Some cultivars of D. alata contain 6 to 38 percent of tannin which is used in Southeast Asia for tanning fishing nets and in Taiwan for tanning leather, to which it imparts a red colour (Coursey, 1967).

There are many traditional medicinal uses of some species of Dioscorea among Africans, Chinese and Asians which were discovered by trial and error. The Zulus use an extract of D. sylvatica for the treatment of uterine and mammary disorders in cattle. More work is needed in this area. Apart from the academic interest, the practical rewards in pharmacy and medicine could be farreaching as in the case of the Indian snake-root, Rauwolfia serpentine Beuth. This was used for many years in traditional medicine by the Indians. It contains reserpine, which has found great use in modem medicine.

Use of root crops as animal feed

Contents - Previous - Next

A factor restricting the development of animal production in many developing countries is the cost of imported feed which has often gone up several fold because of alterations in the rate of exchange of local currency with respect to world markets. As feed costs have increased, animal products have become very expensive. If part of the feed could be substituted with root crops such as cassava, then part of the maize ration could be freed for human consumption. Table 8.1 compares the nutritive value of different cassava products with sorghum and maize, as components of animal feeds. The low protein and fibre and high content of soluble carbohydrates (high digestibility) are notable features of the cassava root. Cassava tops, stems and leaves are also available as animal feed and are comparatively high in utilizable protein.

TABLE 8.1 - Nutritive value of different cassava products compared with sorghum and maize (in percentages)

	Cassava	Cassava	Cassava	Cassava	Sorghum	Maize

	chips	meal	refuse (fresh)	flour	(ground)	
Fresh						
moisture	11.7	11.2	80.0	14.9	11.9	13.4
C. protein	1.9	2.6	0.4	0.3	7.5	9.4
C. flbre	3.0	5.6	1.6	0.1	2.0	1.9
sol. carbohy.	80.5	73.9	17.6	84.4	74.6	70.1
ether ext.	0.72	0.55	0.10	0.10	2.32	3.64
ash	2.17	6.10	0.30	0.20	1.65	1.62
Dry						
total dry matter	88.3	88.6	20.0	85.1	88.1	86.6
C.I. (dry matter basis)	2.1	2.9	2.0	0.4	8.5	10.0
Calculated digestible nutrients						
C. protein	1.3	1.7	0.1	0.2	39.0	7.4
C. fibre	2.3	4.3	1.3	0.1	1.1	0.7
sol. carbohy.	78.9	72.4	9.9	86.3	48.5	64.5
ether ext.	0.36	0.28	0.10	0.10	1.35	2.18

Digestibillity coefficient used						
C. protein	-	-	-	66	52	-
C. fibre	-	-	-	100	57	-
sol. carbohy.	-	-	-	99	65	-
ether ext.	-	-	-	100	58	-
Starch equivalent	83.2	78.7	11.5	84.1	89.5	78.2
Nutritive value	63.1	45.5	114.3	419.6	1.4	8.9

Source: H.K. Lim. 1967.

The International Development Research Centre in Canada sponsored a series of investigations into the use of cassava as animal feed. On the basis of their findings it is recommended that cassava could be a substitute of up to 40 percent for maize in the nutritionally balanced rations of pigs without any deleterious effect, and up to 30 percent in poultry rations.

Gmez et al. (1984) in Colombia reported that when cassava was substituted for corn in a poultry broiler ration at levels of up to 30 percent there was no significant difference in the performance at all levels, but the 20 percent level of substitution was the most economical. It required 215 kg of feed to produce 100 kg live weight with a 20 percent substitution, whereas it required 220 kg and 224 kg respectively for the corn feed and the 30 percent substitution feed as shown in Table

8.2. High levels of cassava intake are more acceptable for broiler production than for laying hens. Egg production and quality may be adversely affected by nutritional imbalances associated with rations high in cassava.

In the case of pigs (Table 8.3) the performance was progressively better as the level of cassava in the feed was increased. Thus it required 339 kg of feed to produce 100 kg weight with corn alone, whereas it required 337 kg and 331 kg respectively with 20 percent and 30 percent cassava substitution. In the economic assessment of the rations, the least-cost broiler diets containing 20 percent cassava meal gave the largest returns while profitability increased with the level of cassava meal in the case of the pig trials (Table 8.4), with those on the 30 percent cassava substitution being the most economical.

In view of the potential value of cassava to supply energy to dairy cattle, it has been used in a great number of experiments as the main source of energy, resulting in higher milk and fat yields and live weight gains (Pineda and Rubio, 1972). Similar results have been obtained for beef cattle when steers fed on commercial concentrate and cassava-based diets gained significantly faster than those fed bran or corn and cob-based diets. Better performance of bulls has also been reported by Montilla et al. (1975) on 40 percent cassava rations rather than on maize meal. Devendra (1977) has reported similar findings for goats and sheep, cassava enhancing utilization and hence nitrogen retention.

TABLE 8.2 - Performance of broilers fed least-cost diets with varying levels of cassava meal

	Cassava meal in diets (percentages)

	0	20	30	SD
Chicks at end of trial (no.)	141	140	137	...
Morality	4.7	5.4	7.4	...
Av. body wt/chicken (kg)				
at 7 wk	1.69	1.75	1.63	.05
at 8 wk	2.01	2.08	1.97	.08
Feed consumed/chicken (kg)				
0-7 wk	3.64	3.69	3.58	.13
0-8 wk	4.61	4.74	4.57	.18
Feed conversion				
0-7 wk	2.20	2.15	2.24	.04
0-8 wk	2.34	2.33	2.36	.04

Pooled standard deviation = Error mean square.
Initial number of chicks per treatment: 148 with an overall average body weigh of 36.3 +(-) 5g.
Units of feed consumed per unit of body weight grin.
Source: Gmez et al., 1984.

Mattei (1984) designed a simple cassava chipping machine for production of chips for animal feed. In one version the chipper is powered by an electric motor and in the other version, by a two-stroke or four-stroke petrol engine, each with a chipping capacity of 1 tonne of cassava per hour. The drying is done on trays made of aluminium mosquito netting supported by chicken wire stretched on a strong timber frame. The dried chips are then stored in a wellventilated area to avoid moulding. The economics of the process are favourable. A good review of simple technologies for root crop processing is provided by the United Nations Development Fund for Women (UNIFEM) publication Root crop processing, 1989.

TABLE 8.3 - Performance of growing finishing pigs fed least-cost diets with varying levels of cassava meal

	Cassava meal in diets (percentages)			
	0	20	30	SD
Pigs/group (no.)	11	12	12	...
Av. final wt/pig (kg)	89.9	94.7	91.1	2.20
Av. daily gain (kg)	0.77	0.82	0.78	0.02
Av. daily feed (kg)	2.55	2.77	2.54	0.06
Feed conversion	3.39	3.37	3.31	0.10

Overall avg initial weight: 20.0 +(-) 1.2 kg. Experimental period: 91 days

Pooled standard deviation = Error mean square.
One pig was eliminated during the first two weeks of the experiment.
Source: Gmez e, al., 1984

Some work has also been reported on the use of sweet potato as animal feed. Yang (1982) found it satisfactory for horses, mules and hogs, for lactating dairy cows when compounded with corn meal feed, and for poultry feed at 25 percent substitution for corn. Yeh et al. (1978) found that the digestible energy and the metabolizable energy are 91 percent of those of corn, and the nett energy is about 79 percent of that of corn as pig feed. It is not as good as corn in terms of quantity or quality of digestible protein or energy. Results in Table 8.5 indicate that sweet potato at less than 25 percent substitution will give a better result than corn alone and al about 25 percent will give a similar weight gain and efficiency as corn. Popping the chips improved starch and nitrogen digestibility as well as removing the trypsin inhibitor which might have contributed to the lowering of the feed value, but it also resulted in reducing the lysine availability. There was a significant improvement in the performance of the pig on the popped food compared to the untreated sweet potato chips. The result is also comparable to the corn diet, which improved quality and percentage lean cut, especially at the 50 percent substitution level.

TABLE 8.4 - Economic assessment of poultry piq-feeding triads

	Cassava meal in diets (percentages)		
	0	20	30
Poultry trial - lot of 1000 chicks at 7 weeks			

Chicks and fixed costs	48 600	48 600	48 600
Feed cost	74 310	77 060	74 580
Interest on working capital	9 218	g 425	9 239
Total expenses	132 128	135 085	132 419
Live broilers at $Col 100/kg + liner ($Col 1 220)	161 770	167 470	152 810
Net return	29 642	32 385	20 391
Return, % of expenses	22.4	24.0	15.4
Pig trial - lot of 10 pigs			
Weaned pigs at $Col 170/kg	33 830	34 170	34 000
Fixed costs, estimated	7 550	7 550	7 550
Feed cost	42 270	44 239	39 983
Interest on working capital	8 365	8 596	8 153
Total expenses	92 015	94 555	89 686
Live pigs at $Col 120/kg	108 000	114 000	109 200
Net return	15 985	19 445	19 514
Return, % of expenses	17.4	20.6	21.8

Results of biological evaluations have been used in these calculations. The figures are in Colombian pesos.
Includes $Col 28 800 and $Col 19 800 for cost of 1 000 one-day-old chicks and fixed costs for raising them, respectively.
See text for explanations.
Source: Gmez et al., 1984

TABLE 8.5 - Performance of fattening pigs on different proportions of corn and sweet potato chips

Corn (% in diets)	Sweet potato chip& (% in diet)	Daily gain (kg)	Feed/ gain (kg/kg)	Source
65 - 83	0	0.53	3.93	Koh et al., 1960
0	56 - 72	0.37	4.79	
30 - 39	30 - 39	0.48	3.83	
63 - 81	0	0.65 ab	3.38	Tal & Lei, 1970
45 - 58	15 - 20	0.66 a	3.37	
29 - 37	29 - 37	0.62 b	3.54	
14 - 18	42 - 54	0.58 c	3.74	
0	54 - 68	0 56 d	3 81	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

72 - 84	0	0.60 a	3.08 b	Yeh et al.,1979
35 -41	35 - 41	0.48 c	3.84 b	
0	69 - 81	0.44 e	4.08 a	
69 75	0	0.69 a	2.95 b	Yeh et al., 1980
0	63 - 68	0.60 c	3.37 a	
33 - 36	33 - 36	0.66 b	3 13 b	
72 - 84	0	0.56	3.14	Lee & Lee, 1979
35 - 41	35 - 41	0.49	3.71	
0	69 - 81	0.48	3.80	

Values in the same column followed by different small letters differ significantly (P<0.01 or P<0.05)
Source: Yeh, 1982.

Chen et al. (1979) evaluated the efficiency of gelatinization of urea-sweet potato meal (GUSP) and found that came on soybean meal performed better than on GUSP or urea alone, but the feed value of GUSP was better than urea. In terms of digestibility of dry matter, crude protein, crude fibre and nitrogen retention GUSP was equivalent to soybean meal. Table 8.6 summarizes the different results obtained using sweet potato for different livestock indicating that replacement of corn by dehydrated sweet potato in the food of dairy cows could give as much milk (91-100 percent) as corn alone (Masher et al., 1948; Frye et al., 1948). If the orange-flesh variety is used the milk will contain more vitamin A and 30 percent more beta-carotene than milk produced

using corn alone, another added advantage. Southwell et al. (1948) found that beef cattle fed standard rations gained 1.07 kg/day compared to 1.17 kg and 0.98 kg/day when half or all of the corn is replaced with sweet potato respectively. The feed gain ratios were 9.51, 9.31 and 9.22 respectively. Massey (1943) found in a three-year trial that substitution of corn with sweet potato led to more meat production in lamb. Lee and Young (1979) reported that chickens fed diets containing a 24 percent substitution of corn with sweet potato grew as well as on the all-coin diet, with no significant difference in carcass quality, and the egg yolk contained more vitamin A.

TABLE 8.6 - Value of sweet potato as compared to corn In various feeding trials

Animal	Substitution for corn	Comparative value	Parameter compared
Young chicks	Up to 60%	nsd	Wt gain
Came	100% root trimmings	80%	Wt gain
Cattle	50%	nsd	Wt gain
Dairy came	100%	nsd	Milk product/on
Dairy came		91%	Milk production
Dairy came		88%	Milk production
Dairy came	50%	97%	Milk production
Lambs, steers	100%		Digestibility
		92%	

Chicks	10 or 20%	nsd	Wt gain
Dairy came	100%	nsd	Milk production

Sources: Yeh & Bouwkamp, 1985.

Contents - **Previous** - **Next**