Tropical Root Crops

Production and Uses in Africa

Proceedings of the International Symposium of the International Society of Tropical Root Crops —
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The International Society for Tropical Root Crops — Africa Branch was created in 1978 to stimulate research, production, and utilization of root and tuber crops in Africa and the adjacent islands. The activities include encouragement of training and extension, organization of workshops and symposia, exchange of genetic materials, and facilitation of contacts between personnel working with root and tuber crops. The Society’s headquarters are at the International Institute of Tropical Agriculture in Ibadan, Nigeria, but its executive council comprises eminent root and tuber researchers from national programs throughout the continent.

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TROPICAL ROOT CROPS: PRODUCTION AND USES IN AFRICA
ABSTRACT

A mixture of original research, updates on procedures, literature reviews, and survey reports, this document resulted from the second symposium of the International Society for Tropical Root Crops — Africa Branch, with 77 participants from 16 countries. The focus was cassava, yams, cocoyams, and sweet potatoes, from the perspectives of breeders, agronomists, soil specialists, plant pathologists, entomologists, nutritionists, food technologists, etc. Learning from past successes and failures, many of the researchers directed their efforts toward problems obstructing progress in reaching improved production and use of root crops and attempted to view, realistically, the context in which their results would be applied.

RÉSUMÉ

Résultats de recherches récentes, mises à jour sur les méthodes de recherche, revues de publications et rapports de sondages sont contenus dans ce document issu du Deuxième symposium de la Société internationale pour les plantes-racines tropicales — Direction Afrique, qui a réuni 77 participants de 16 pays. Des communications sur le manioc, le taro, le yam et la patate douce ont été présentées par des phytoselecteurs, des agronomes, des pédologues, des phytopathologistes, des entomologistes et des spécialistes de la nutrition et des aliments, entre autres. Tirant leçon de leurs succès et de leurs échecs, beaucoup de ces chercheurs ont dirigé leurs efforts vers la solution des problèmes qui entravent l’augmentation de la production et de la consommation des plantes-racines et ont tenté de considérer d’un œil réaliste le contexte qui sera celui de l’application de leurs recherches.

RESUMEN

Una mezcla de investigaciones originales, actualizaciones de procedimientos, reseñas de literatura e informes de encuestas, este documento es el resultado del segundo simposio de la Sociedad Internacional de Raíces Tropicales, Filial Africana, que contó con 77 participantes de 16 países. El simposio se centró en la yuca, el taro, el cocoíame y las batatas, desde la perspectiva de los fitomejoradores, los agrónomos, los especialistas en suelos, los patólogos vegetales, los entomólogos, los nutricionistas, los tecnólogos alimenticios, etc. A partir de los éxitos y fracasos anteriores, muchos de los investigadores encaminaron sus esfuerzos hacia los problemas que obstaculizan el avance para lograr una producción y un uso mejorados de las raíces y trataron de obtener una visión realista del contexto en que los resultados pueden ser aplicados.
TROPICAL ROOT CROPS: PRODUCTION AND USES IN AFRICA

EDITORS: E.R. TERRY, E.V. DOKU, O.B. ARENE, AND N.M. MAHUNGU

PROCEEDINGS OF THE SECOND TRIENNIAL SYMPOSIUM OF THE INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS — AFRICA BRANCH HELD IN DOUALA, CAMEROON, 14 – 19 AUGUST 1983
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POTENTIAL UTILIZATION OF MAJOR ROOT CROPS, WITH SPECIAL EMPHASIS ON HUMAN, ANIMAL, AND INDUSTRIAL USES

D.G. COURSEY

Root crops in developing countries are mainly used for human food. Most are still grown by small-scale farmers, who operate within the subsistence economy, with only limited off-takes of produce to the market economy supplying the rapidly growing urban centres. With cassava in much of Latin America, yams in West Africa and the Caribbean, and taro in the Pacific, a trend exists, and may be expected to increase with further urbanization, toward semicommercial or commercial production, together with the development of more sophisticated marketing systems. Yams and, in most circumstances, taro, other aroids, and minor root crops command too high a price for significant amounts to be available for uses other than human food, although peelings, waste, etc. are used as animal feed within subsistence economies. Cassava is in a completely different category, the costs of equicaloric amounts being only about one-fifth of those of yam. Similarly, sweet potato, with two to four crops per year, is productive and like cassava is seldom a preferred food. These two crops can, therefore, supply substantial surpluses beyond food demands; the former, especially, is already being exploited for animal feed, edible and industrial starch, and other derived products. Although alternative uses of tropical root crops will probably increase, their primary role is likely to remain as human food in producing countries.

"Tropical root crops" could be defined in many ways, but most workers accept that the phrase refers to staple foods grown in tropical or near-tropical conditions where the edible organ — root, stem, tuber, etc. — is subterranean (hypogeous) (Table 1). I will confine my discussion to those that are used as major providers of carbohydrate in the diet and largely take the place of grains — wheat, barley, maize, sorghum, millets, and rice — in other agricultural economies.

At the sixth international symposium on tropical root crops in Lima, Peru, in February 1983, considerable criticism was directed at the value of existing statistics, the theme being that where a substantial proportion of a crop is grown within a subsistence economy, as applies to so much of tropical agriculture, a degree of under-reporting of production is likely to occur. However, the current overall pattern is not vastly different from that reported more than a decade ago (Coursey and Haynes 1970), allowing for increases in population and advances in agricultural practice.

CIRCUMSTANCES AND TYPE OF UTILIZATION

Before proceeding to the main topic, I believe it appropriate to set the scene of production and also refer to some of the social changes that relate to root-crop utilization. First, the ecological conditions of growth. The work of Flach (1979), following preliminary studies by de Vries et al. (1967), indicated that root crops are produced mainly in the humid equatorial areas and the subhumid savannas adjacent to the equatorial zone. There are exceptions, however, particularly the potato, which, although native to highland equatorial tropics in the Andean altiplano, has been developed most successfully as a temperate crop; only recently is it returning to the tropics. The sweet potato is a short-term crop that matures in 3–5 months and is extensively grown in subtropical or warm temperate areas.

Tropical root crops were essentially products of subsistence agriculture until 2 or 3 decades ago. A large proportion of the crops was consumed by the farmer's immediate and extended families; only modest quantities were taken for marketing, even for exchange in neighbouring villages. Outside Latin America, few substantial

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cities existed in the root-crop-growing areas of the tropics, and only limited urban demand was generated. This situation has changed rapidly over the last few decades, with the urban population growing about twice as fast (5% compared with 2.5%) as the total population.

This not only implies an increase in the need to supply the consumptions but also a relative (although not absolute) reduction in the food-producing rural population. Although in many parts of Africa the traditional subsistence pattern may be expected to persist for a considerable period, the trend toward urbanization can be expected to continue.

FAO (1982b) has estimated that, whereas only 28% of inhabitants of the developing world lived in urban centres in 1975 (in itself a great increase on figures for 10 years before), by the year 2000 the figure can be expected to reach 44%, i.e., nearly half the population of the developing world. The transportation of perishable material such as root crops from rural to urban centres is a much more difficult problem than the transportation of grains and other durables. The technical problems associated with long-distance transport of perishable food crops such as root crops have been discussed elsewhere (Coursey 1983a). Transportation considerations are inextricably linked to processing, as transporting food that has low moisture and high stability is obviously more facile than moving a bulky, awkward, easily damaged material that contains substantial amounts of water and waste.

The mechanized processing of root-crop products, particularly yam and cassava, has come, especially in West Africa, to be regarded as a universal panacea for transportation problems: in fact, very little practical success has been achieved. Many factors, mainly of an economic nature, are involved as farmers are reluctant to sell their crops for processing to a large factory whose presence they often regard as alien and suspect. Organoleptic problems have arisen, as the products of some of the pilot-scale operations have not accorded with traditional tastes. New attempts are being made to mechanize processing, but no substantial commercial success has yet been obtained. This contrasts markedly with the situation in developed countries, where substantial quantities of both *Solanum* and sweet potatoes are processed into flakes or powders that can be easily reconstituted with water and also into crisp, deep-fat-fried and dehydrated products for which the tropical root crops are also quite suitable. Such fried products, mainly from yams, are indeed manufactured, especially in the Caribbean but, so far, only in cottage industries. Brief mention must be made of the success in Hawaii of producing a traditional foodstuff, poi, from *Colocasia*

### Table 1. Tropical root-crops production in developing countries.

<table>
<thead>
<tr>
<th>Common names</th>
<th>Botanical names</th>
<th>Production (10^6 t/year)</th>
<th>Edible organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava (tapioca, manioc, mandioca, yuca)</td>
<td><em>Manihot esculenta</em> Crantz (often incorrectly. <em>M. utilisima</em> Pohl.)</td>
<td>127</td>
<td>Root</td>
</tr>
<tr>
<td>Yam (igname, íname)</td>
<td><em>Dioscorea rotundata,</em> <em>D. cavenensis,</em> <em>D. alata,</em> <em>D. esculenta,</em> <em>D. dumetorum,</em> minor <em>Dioscorea</em> spp.</td>
<td>18–22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Stem, hypocotyledonary tuber</td>
</tr>
<tr>
<td>Sweet potato (batata)</td>
<td><em>Ipomoea batatas</em></td>
<td>18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Root tuber</td>
</tr>
<tr>
<td>Potato (white, Irish)</td>
<td><em>Solanum tuberosum</em> (and <em>S. tuberosum × S. andigenum</em> hybrids)</td>
<td>36&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Stem tuber</td>
</tr>
<tr>
<td>Taro (dasheen, cddoc. old cocoyam)</td>
<td><em>Colocasia esculenta</em></td>
<td>4–6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Corm, cormel</td>
</tr>
<tr>
<td>Tannia (ocumo. new cocoyam)</td>
<td><em>Xanthosoma sagittifolium</em></td>
<td>1–2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Corm, cormel</td>
</tr>
<tr>
<td>Elephant yam</td>
<td><em>Amorphophallus campanulatus</em></td>
<td>1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Corm</td>
</tr>
<tr>
<td>Giant taro</td>
<td><em>Cyrtosperma spp., Alocasia spp.</em></td>
<td>1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Corm</td>
</tr>
</tbody>
</table>

<sup>a</sup>FAO (1982a) estimate does not include production in China.
by a partially mechanized process; in developed countries there is greater emphasis on the production of convenience foods.

The traditional storage techniques that are entirely adequate in subsistence agriculture (Coursey 1982) may not apply to situations where remote urban markets are being supplied. In spite of this, the extreme ingenuity of farmers and intermediaries in dealing with traditional crops must never be forgotten: when the first European contacts were made with West Africa in the late 1400s, coastal settlements, such as the modern Bonny, in Nigeria, were being supplied with yams brought “hundreds of leagues” by canoe by inland waterways (Coursey 1967b).

A topic that has received much attention of late is the incorporation of root crops, usually for economic reasons cassava, into composite flours for making bread or other bakery products. Many investigations have been done, and, from the technical point of view, there is usually no difficulty in replacing 10–30% of the constituents with root-crop material for bread making and even larger amounts for pastry and similar products.

The factors that have prevented the widespread adoption of composite flours have been economic rather than technical and are similar to those that affect almost any large- or medium-scale operation based on root crops in developing countries, i.e., the difficulty of obtaining adequate supplies of raw material at an economic price. Indeed, in some countries, bread containing cassava is favoured and commands a higher price than conventional bread, and attractive bakery products can be made with yam and sweet potato where economically possible. The basic requirements for programs based on composite flour have recently been discussed by Crabtree and James (1982), and Dendy et al. (1971) reviewed earlier work. The use of cassava, economically the most attractive material, has been discussed by Crabtree et al. (1978), introducing the interesting concept of blending peeled, mashed cassava with wheat flour to eliminate the drying stage of the cassava before its utilization, as it appears illogical, unless shelf-life or transport is a consideration, to dry a material and then add water to the dough that is being prepared.

All that has been said has indicated that the major use of tropical crops is as human food: this is in fact the case.

The second most important use of tropical root crops is animal feed, but this is distinctly limited. In many societies, crops are too highly valued as human food to be diverted to other purposes (other than peelings and wastes, which could be a valuable by-product if successful factories were ever established), and it is only the cheaper crops that can be used for nonfood purposes.

The only other industrial use of the tropical root crops is the manufacture of starch, which is the major constituent of the economic organs of the crops concerned. In some countries, commercially successful starch industries using high technology have been established, usually based on cassava as the cheapest raw material. In some cases, such as Thailand, factories are operating to produce starch for export, whereas in other countries, such as Nigeria, import substitution is the main goal. There is also considerable production of starch at artisanal levels for nonfood use, especially the starching of clothes after laundering (Jones 1983).

In Japan, sweet-potato starch and, in Europe, potato starch are important industrial-scale commodities. There is no inherent reason that starch, especially from sweet potatoes, should not be manufactured in larger quantities in the developing world. Other possibilities exist for proceeding from starch to glucose syrup for fermentation, but only one or two industrial operations have been established for this purpose. Phillips (1974) has estimated that only 1% of cassava production is diverted into industrial uses other than animal feed, and, for the other root crops, the figure would be substantially less.

Cassava

Not only is cassava the most important root crop of the tropics, its production (Table 2) being much greater than all others put together; it is also the most ubiquitous and is grown almost everywhere where ecological conditions permit. It is essentially a tropical crop, although some cultivars can withstand light frost, e.g., in southern Brazil, parts of Argentina, and Zambia (Montaldo 1979). Traditionally, cassava has been processed at an artisanal level, often into dried products; the history of such processing goes back probably about 4000 years to the domestication of the crop in northern South America (Lancaster et al. 1982). The various methods of utilization as food have been fully reviewed recently by Lancaster et al. (1982). A very large proportion of the total crop is consumed in the production areas, although in countries such as...
Brazil and much of West Africa, where traditionally it is processed into dry products, substantial long-distance trade in the products exists (Coursey 1978a; Lancaster et al. 1982). The toxicity of many cultivars of cassava and the inherent perishability of the roots provided a double incentive to the development of simple processing techniques. Modifications of which are now used in very many parts of the world. In West Africa particularly, a great part of the cassava crop is processed and traded in the form of gari or sometimes other dried products (Coursey 1978a). Although the use of cassava as food is continuously being condemned on the basis of its low-protein and high cyanogenic-glucoside contents, both these factors have probably been greatly overrated. Cassava should be regarded as a source of carbohydrate and little else (small quantities of vitamins and minerals) and should be used, like any starchy food, in a diet that is adequate in protein from other sources. Only in extremes of poverty where people are forced to eat cassava and little else does serious protein deficiency or cyanide toxicity arise (Cooke and Coursey 1981; Delange and Ahluwalia 1982). Nevertheless, the increase in kwashiorkor in Africa and other parts of the world may be partly caused by displacement of the protein-rich yam by the much cheaper cassava. Similarly, toxicity may well have been substantially exaggerated. First, there is a wide range in cyanide content among cassava cultivars, and the widely held belief that cyanide content is directly related to plant vigour appears to have little foundation in fact. Chronic cyanide poisoning tends to be associated with famine when intake of protein and sulfur is insufficient. Furthermore, it is most likely to happen in areas where soil deficiencies induce iodine deficiency in the population, as the thiocyanate formed in the body during the detoxification of the cyanide can interfere with iodine metabolism (Nestel and MacIntyre 1973; Cooke and Coursey 1981; Delange and Ahluwalia 1982).

Cassava is unique among tropical root crops in that it has substantial potential for use as animal feed. Dried cassava, in the form of meal and chips, has been exported in small quantities from many tropical countries, including Brazil, Madagascar, Indonesia, and Thailand, for many years (ICM 1949), but the total amounts appearing in trade internationally were comparatively limited and quality was usually exceedingly poor until recently. In the mid 1960s, Thailand started to develop an export trade in dried cassava products, initially in dried chips and the meal prepared from them. This trade was initially almost entirely with the “Old EEC” (European Economic Community) countries, and, in fact, Germany, Belgium, and Holland are still the main importers. This market was created artificially by factors within the Common Agricultural Policy (CAP) of the EEC, which enabled substitutes for grain to be imported at low duty. These exports rose from less than $0.5 \times 10^6$ t of dried products annually in 1962 through $1.5 \times 10^6$ t 10 years later to $5-7 \times 10^6$ t in the later 1970s or early 1980s. During the same period, a change in practice occurred, and, now, dried ground cassava is also pelleted under heat and pressure with the addition of a binder to make it more appropriate for incorporation into animal feed and also to ease shipment (Phillips 1974; UNCTAD 1977; Walters 1983). Thailand is an exception to the rule in that little of its cassava is used for local human food; indeed Thailand has been able to build up this substantial export trade largely because there is minimal competition from local food markets. It is exceedingly difficult to support any cassava-based operation at the industrial or export level in countries where such a demand exists. During the late

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**Table 2. Cassava production and utilization in major producing countries (FAO 1982a)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (10^6 t)</th>
<th>% of global total</th>
<th>Production (kg/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total developing countries</td>
<td>127.261</td>
<td>100.0</td>
<td>38.2</td>
</tr>
<tr>
<td>Brazil</td>
<td>25.050</td>
<td>19.7</td>
<td>200.0</td>
</tr>
<tr>
<td>Thailand</td>
<td>17.900</td>
<td>14.1</td>
<td>371.9</td>
</tr>
<tr>
<td>Indonesia</td>
<td>13.726</td>
<td>10.8</td>
<td>91.2</td>
</tr>
<tr>
<td>Zaire</td>
<td>13.000</td>
<td>10.2</td>
<td>446.7</td>
</tr>
<tr>
<td>Nigeria</td>
<td>11.000</td>
<td>8.6</td>
<td>138.1</td>
</tr>
<tr>
<td>India</td>
<td>5.817</td>
<td>4.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Tanzania</td>
<td>4.650</td>
<td>3.6</td>
<td>251.1</td>
</tr>
<tr>
<td>Vietnam</td>
<td>3.400</td>
<td>2.6</td>
<td>61.9</td>
</tr>
<tr>
<td>China</td>
<td>3.276</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Mozambique</td>
<td>2.850</td>
<td>2.2</td>
<td>264.9</td>
</tr>
</tbody>
</table>
1960s and early 1970s, much interest was shown by official and commercial bodies in many tropical countries in establishing exports of dried cassava to Europe, but none of these projects had any real hope of success in view of the competition in price from local markets for either fresh or traditionally processed cassava. A small proportion of the cassava pellets in international trade derives from Indonesia, but the market is dominated by Thailand, which has made massive investments in port facilities for bulk handling. Cassava is the third largest of Thailand’s exports, and there is serious concern there that, through changes in the economic policies of the EEC, a quota system will reduce cassava imports from nearly $7 \times 10^6$ t in 1981 (Braude 1982) to $5 \times 10^6$ t in 1984 and $4.5 \times 10^6$ t in 1986.

Along with the export of cassava products for animal feed, there is a growing interest in exporting fresh cassava for human food to urban centres either in producer or neighbouring countries or in countries where there are cassava-consuming immigrants. A substantial industry exists in Latin America, particularly Costa Rica, to supply North American and, to a lesser degree, European markets with deep-frozen, peeled cassava roots, and these can be obtained in most supermarkets where there are immigrant populations. At the same time, a smaller amount of fresh cassava roots packed in absorbent material is exported. It is now possible to buy fresh cassava roots in British urban markets, something that could not have been done even a few years ago.

Cassava is used as animal feed in many producer countries, especially in Latin America, and in general satisfactory results have been obtained, although problems, particularly of acceptability, still exist (Nestel and Graham 1977). The pig in particular seems to be exceedingly resistant to cyanide, and the incorporation of cassava into pig rations appears to present few problems. The burgeoning poultry industry of the developing world presents another opportunity for cassava’s use as animal feed. The problems will probably be more economic than technical in any country where a substantial demand for cassava for human food exists. Also, if cassava is being introduced into compound feed in place of barley or maize, larger amounts of protein will have to be incorporated to make up for the minimal amounts of protein contributed by the cassava to the ration.

Cassava-based starch industries have been set up both at industrial and, much more widely, at artesan levels in many countries of the world, generally using some form of wet extraction and settling process (Phillips 1974; Jones 1983; Walters 1983). This utilization is currently only about 1% of the total world crop and is not likely to increase very substantially in the near future. One or two factories exist in developing countries that take the starch a further stage to glucose syrup, but any industrial activity in countries where cassava is eaten will always suffer economic problems associated with competition from local food markets.

Since the rapid escalation of energy costs, especially liquid fuel, considerable attention has been given to cassava as a source of ethanol. Brazil, in particular, has put enormous efforts into the production of alcohol for power purposes from biological resources, although more effort has been put into sugarcane than into cassava: there is one plant operating in Brazil utilizing cassava, whereas many utilize sugarcane. The disadvantage in using cassava instead of cane is that it must undergo amylolysis before alcoholic fermentation, but cassava has the advantage of being capable of growing on marginal soils and under poor conditions. Currently, the energy costs of producing a litre of power alcohol from cassava appear to be of the same magnitude as, or even slightly higher than, the calorific value of the product. Thus, this particular use of cassava would make sense only when oil prices have risen higher and the premium on portable liquid energy is greater than it is today (Dominguez 1983).

YAMS

Yams are botanically very different from cassava as is their utilization. In all societies where they are major crops, mainly West Africa, Melanesia, and the Caribbean, they are crops of prestige: their cost in equicaloric terms is anything from three to five times that of cassava (Coursey 1967b, 1978b). They are ancient crops and, within the cultures in which they are grown, have acquired a heavy burden of religious and magical significance that hardly applies to any other tropical crop (Coursey 1978b, 1981). In practically all the areas where they are grown, they are the preferred staple food, and this contributes to their high unit cost. Unlike cassava, they need rich soil, a lot of attention in cultivation, and substantial labour in harvesting and storage. Against this background, it is almost impossible to consider yams for any purpose other than human food. The only caveat on this is that, in traditional societies, yam peels and
waste are often thrown out to feed livestock, especially goats and chickens. If a yam-processing plant were successfully set up, the use of the peel for animal feed could affect overall economics. Nevertheless, the main purpose of the yam must continue to be to provide human food at, regrettably, increasing real prices.

In spite of many warnings that yam production is declining in West Africa, the best FAO statistics that existed up to 1977, when yam ceased to be counted as a separate crop, suggested that global yam production (essentially West Africa) has increased very slightly (Table 3).

The genus *Dioscorea* contains approximately 600 species, but only a small proportion of these are utilized as food. Probably between 50 and 100 species in all are eaten on occasion, some being collected from the wild and used only in times of famine. World yam production derives mainly from the *D. rotundata*—*D. cayenensis* complex, from *D. alata*, and from *D. esculenta*. *Dioscorea dumetorum* has special importance in Cameroons. Other species are of substantial local importance. Nigeria alone produces almost three-quarters of the yams in the world, whereas the countries of the "yam zone"—Nigeria, Benin, Togo, Ghana, and Ivory Coast—produce together more than 90%. A number of small countries in which yams are very important, such as Tonga and Barbados, have not been included because their contribution to global production is small. One developed country, Japan, produces approximately the same quantity of yam as Jamaica but grows a temperate species, *D. opposita* (commonly but incorrectly known as *D. batatas*). It is not a staple food in that country but rather is grated and used as a condiment in small quantities with other foods (Kawakami 1970).

Although most of the yams produced are consumed locally, there is a long tradition of movement of yam between rural areas and urban centres in West Africa and between islands in the Caribbean and in the South Pacific (Coursey 1978a).

Appreciable quantities are shipped to developed countries for the use of African and Caribbean ethnic minorities living there. For example, about 8000 t go to Britain annually (Bell and Coursey 1970); originally from Nigeria, now *D. rotundata* and *D. cayenensis* come principally from Brazil and Jamaica, whereas some *D. alata* comes from Barbados. The yam tuber, being a dormant organ, is almost ideally suited for storage and transportation. Only in some Yoruba-speaking areas of western Nigeria and in parts of Ghana is a large proportion of the yam crop processed into dried pieces or meal. Traditional processes involve parboiling yam slices, drying them in the sun, and then pounding them with a wooden mortar and pestle into a coarse flour, known in Yoruba as amala. In other yam-growing areas, such yam flour is made only from yams that are found to be rotten at the time of harvest or that, for some other reason, are unsuitable for storage or immediate use. Such flours, however, are made in almost all yam-growing areas of the world (Coursey and Ferber 1979).

Yams are used in many culinary ways, with great differences in species, and even cultivars, on account of the wide variation in starch granular and rheological properties. The most favoured yam-based food in most of West Africa is the heavily pounded dough known as fufu, which is best when prepared from *D. rotundata*, with its high starch viscosity and gelatinization strength. Fufu suffers from what appears to be a rapid drying out within a few hours of preparation but what is actually an effect of the ex-

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Table 3. Yam production and utilization in developing countries (FAO 1975).

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (10^6 t)</th>
<th>% of global total</th>
<th>Utilization (g/person/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigeria</td>
<td>15.00</td>
<td>74.3</td>
<td>652</td>
</tr>
<tr>
<td>Ivory Coast</td>
<td>1.70</td>
<td>8.4</td>
<td>695</td>
</tr>
<tr>
<td>Ghana</td>
<td>0.80</td>
<td>3.9</td>
<td>222</td>
</tr>
<tr>
<td>Togo</td>
<td>0.75</td>
<td>3.7</td>
<td>914</td>
</tr>
<tr>
<td>Benin</td>
<td>0.61</td>
<td>3.0</td>
<td>543</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>0.27</td>
<td>1.4</td>
<td>26</td>
</tr>
<tr>
<td>Sudan</td>
<td>0.26</td>
<td>1.3</td>
<td>47</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>0.17</td>
<td>0.8</td>
<td>169</td>
</tr>
<tr>
<td>Jamaica</td>
<td>0.13</td>
<td>0.7</td>
<td>180</td>
</tr>
<tr>
<td>Guinea</td>
<td>0.06</td>
<td>0.3</td>
<td>34</td>
</tr>
</tbody>
</table>
tremely rapid retrogradation of yam starch compared with other starches (Coursey and Ferber 1979; Coursey 1983b). People accustomed to European diets often consider that *D. alata* tastes better than the *D. rotundata*–*D. cayenensis* group because it (and *D. esculenta*) can substitute for potato and is not greatly dissimilar. The *D. rotundata*–*D. cayenensis* yams, however, have distinctive flavours and textures that make them attractive to those accustomed to them. *Dioscorea dumetorum* is greatly liked among most West Africans for its fine flavour, although it needs to be processed to remove the alkaloid present; it is soft when cooked and is favoured by the elderly or others with poor teeth. Many of the other species, especially those of Southeast Asia and Madagascar, also have distinctive flavours and are highly regarded, as is the American *D. trifida* in the Caribbean.

Recently, there has been much interest in establishing mechanized production of some form of “instant yam,” which could be reconstituted simply with water in a manner comparable with the “instant potato” popular in Europe and North America. The earliest experiments were undertaken in the Ivory Coast in the early 1960s and the product, known as Foutoupret, was alleged to be quite acceptable, although no commercial production developed. In the late 1960s and early 1970s, a factory was established in Nigeria producing a drum-dried flake, sold commercially for several years under the trade name Poundoyam. The reconstituted product fairly closely resembled fufu. The factory went out of production partly because of difficulties of supply of yams to its location near Lagos, remote from major yam-producing areas. At about the same time, a pilot plant, also using drum-drying, was established in Barbados, processing *D. alata*, the aim here being to yield a product resembling mashed potato more than West African fufu. Again, it functioned for several years, also making some sweet-potato flake but eventually closed over problems of supply of raw material. I understand that further attempts are under way in Nigeria to prepare a diced product that reconstitutes to a substance approximating fufu. I would be pleased to receive any information about the development of this new project, especially concerning its commercial success. Fuller details of the earlier attempts at processing yam for human food are given elsewhere (Coursey and Ferber 1979; Coursey 1983b).

Desirable though it may be to produce a convenience food from yam, particularly for modern urban society, the fact remains that there will always be a strong demand in both rural and urban areas for fresh yam. Extension of storage life of fresh yam tubers is still, therefore, a major priority. Apart from mechanical damage inflicted during or after harvesting, losses during storage under the traditional system are caused mainly by preharvest pathogens (Noon 1978), but the ultimate storage life is determined by the inherent dormancy and quality of the yam tuber itself; the length of dormancy is fundamentally important. Many trials have been undertaken with yams using the sprout inhibitors that are traditionally successful with potatoes and are widely used with that crop. All these experiments have been total or near-total failures. The reasons have recently been elucidated (Passam 1982a; Passam et al. 1982); in the yam, the bud primordia for regrowth at the end of dormancy are not formed at harvest as they are with potato, and there is, therefore, nothing on which a sprout suppressant can act. A small extension of dormancy can be achieved if a sprout suppressant is applied at the end of dormancy, and the traditional yam farmers’ practice of removing sprouts manually from the tubers in the barn is believed also to contribute to delaying the breakage of dormancy. Both techniques, however, have only limited application and can delay breakage of dormancy by only a matter of weeks. Variable results have been obtained with gibberellins (Passam 1982a).

A possibility for the extension of the dormant life of yams to supply markets for longer periods is storage at reduced temperature. However, since my initial work (Coursey 1968a), several authors have found that cool storage presents many difficult practical problems at the commercial level. Yams are susceptible to chilling injury, and there is much variation even within a particular batch of a single cultivar in the exact temperature at which chilling injury occurs. With the majority, exposure to temperatures below 10°C, or even 14°C, for any substantial period will result in irreversible biochemical damage that makes the tubers totally unsuitable for human consumption within days of their being removed from cool storage (Adesuji 1982; Demeaux et al. 1982). Being convinced of the limited applicability of cool or cold storage for yams, Adesuji (1982) and Demeaux et al. (1982) independently studied the use of gamma irradiation as an alternative means of extending dormancy. Using gamma dosages of the order of 7.5 krad, they were able to keep the tubers in good condition for 6–8 months. Similar techniques have been used in developed countries for extending the storage life of potatoes.

The only application of yams for industrial
purposes is the manufacture (by a water-extraction and settling process) of starch from *D. hispidu*, an Asiatic species similar to *D. dumetorum* and even more toxic. The total amount of yam devoted to this purpose is, however, quite small, and the industry exists only in the Philippines.

Certain members of the genus Dioscorea are sources of steroids for medicinal purposes, but they are totally different from the edible yams.

**Sweet Potato**

The sweet potato is rather anomalous. Originally a native of Mexico, it is the only economic species among the 300 or so within the genus Ipomoea. It has spread around the tropical and subtropical world in both directions, crossing the Pacific before European-contact times (Yen 1974). It is widely distributed but most (80%) of the world's production originates from China (Table 4). The crop is also quite important in Japan, in the neighbouring Ryukyu Islands, and in the southern states of the USA (Edmond 1971). Southeast Asia (Calkins 1979; Luh and Moomaw 1979; Villareal and Griggs 1982) and highland East Africa comprising Rwanda, Burundi, and Uganda account for a substantial proportion of the production in the tropical world. Throughout New Guinea and Melanesia in general, the sweet potato is becoming more and more important as a result of a lethal virus complex affecting the greatly preferred Colocasia. It is particularly important in the highland areas of New Guinea, where the climate is cool.

Throughout most of the tropics, sweet potato is consumed fresh after boiling, frying, or roasting. The majority of tropical peoples who consume it prefer white-fleshed, starchy cultivars to those that have been developed at considerable expense in the United States to have a high carotene (vitamin A) content. As with all crops, there is a great deal of variation in organoleptic preferences among ethnic groups, but the sweet cultivars from the USA with their fairly strong flavour are unacceptable to tropical populations, especially those who are accustomed to yam. In West Africa in particular, the sweet potato is likely to be popular only among some of the northern ethnic groups. West Africans of the forest and southern savanna would regard such a sweet commodity as being “un-African” and, therefore, suitable only perhaps for children.

Nevertheless, the majority of sweet potatoes produced in tropical countries are used as human food, boiled, fried, or roasted. In the South Pacific, sweet potatoes are often roasted in underground ovens in the same way as Colocasia.

The production potential of the crop is high because as many as four crops can be grown annually in some areas. Thus, sweet potato could be used as an animal feed in developing countries, as it is in the United States. Not only the roots but also the vines can be used, and whole-plant ensilage is a distinct possibility.

Much of what has been done in the southern states of the USA (Edmond 1971) is not applicable to the tropical world. American taste tends to run to the sweeter type of sweet potato, and a substantial portion of the crop grown there is canned in a sugar syrup. Nevertheless, the Caribbean populations in general have lost the traditional African preference for nonsweet foods, and the sweet potato is quite popular in many of

<table>
<thead>
<tr>
<th>Production</th>
<th>10^6 t</th>
<th>% of global total</th>
<th>kg/person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total developing countries</td>
<td>143.7</td>
<td>98.5</td>
<td>43.1</td>
</tr>
<tr>
<td>China</td>
<td>125.7</td>
<td>87.4</td>
<td>124.7</td>
</tr>
<tr>
<td>Vietnam</td>
<td>2.4</td>
<td>1.6</td>
<td>43.7</td>
</tr>
<tr>
<td>Indonesia</td>
<td>2.1</td>
<td>1.4</td>
<td>13.8</td>
</tr>
<tr>
<td>India</td>
<td>1.5</td>
<td>1.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Korean Republic</td>
<td>1.1</td>
<td>0.7</td>
<td>28.3</td>
</tr>
<tr>
<td>Rwanda</td>
<td>0.9</td>
<td>0.6</td>
<td>189.5</td>
</tr>
<tr>
<td>Burundi</td>
<td>0.9</td>
<td>0.6</td>
<td>213.4</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.8</td>
<td>0.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>0.8</td>
<td>0.5</td>
<td>8.8</td>
</tr>
<tr>
<td>Uganda</td>
<td>0.7</td>
<td>0.4</td>
<td>49.9</td>
</tr>
</tbody>
</table>
the islands, with appreciable quantities being exported to North America and to Britain (Bell and Coursey 1970) to provide for the immigrant communities of Caribbean origin living there.

One of the major problems of sweet potato in the tropics is its perishability. Grown under temperate conditions, the only major storage problem is protection from cold, as the sweet potato, like the yam, suffers from chilling injury at about 10°C. In the tropics, however, sweet potatoes are liable to preharvest attack by tuber-boring insects (Cylas and Eucepes) and postharvest decay. As a result of the storage problems, the tropical sweet-potato crop is used shortly after harvest. In the Philippines, superior tubers are set aside for human use immediately after harvest, and the remainder are relegated to stock feed (Villanueva 1969). In highland New Guinea, where sweet potatoes are by far the most important staple, they are commonly cured by being hung up near a fire and, in some cases, even smoked. In New Guinea and other parts of Melanesia, they are commonly fed to pigs — a practice that could be regarded as a way of storing sweet potato in the form of pork consumed at festive occasions (Siki 1979).

**Potato**

*Solanum* potatoes are also something of an anomaly compared with other tropical root crops: although their origin is tropical — only a few degrees south of the equator in the Andean altiplano of Peru and Bolivia — their natural habitat is at such a high altitude that they have adapted very easily to the ecological conditions of the temperate countries and have developed there to a vastly greater degree than they have in the tropical world (Salaman 1949). Nevertheless, their production in the tropical world has increased greatly in recent years (Table 5) and has surpassed yam and sweet potato together, almost doubling in the last decade. Although much of this increase has been in the highland tropics — not only in the original home of the crop in South America but also in countries such as Kenya and India — extensive research has been undertaken and has led to enhanced production under conditions at lower altitudes, sometimes not far above sea level. Much of this work has been initiated or undertaken by the Centro Internacional de la Papa (CIP) in Peru, usually in collaboration with national research organizations (French 1972).

Although in the developed world the potato has many industrial and food-processing uses, including starch and alcohol (Smith 1977), potatoes in the developing countries are almost exclusively eaten fresh. Nevertheless, a change in food usage has taken place in many countries and has resulted in a rapid increase in potato production in the tropical world. As recently as 20 or 30 years ago, the potato was restricted to the highland tropics and, elsewhere, was confined to use by privileged economic groups, especially expatriates. Against this background, merchants could afford refrigerated storage, and producers could tolerate exceedingly low yields. This pattern still exists in some areas, but, in many countries, potato is becoming an everyday staple food of the producer. Kenya and highland India are of particular interest, as the potato is becoming quite widely accepted as a subsistence crop as well as a crop for sale at high prices for luxury markets.

Table 5. Potato production and utilization in developing countries (FAO 1982a).

<table>
<thead>
<tr>
<th>Country</th>
<th>Production</th>
<th>kg/person</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>15.0</td>
<td>14.9</td>
</tr>
<tr>
<td>India</td>
<td>9.6</td>
<td>13.8</td>
</tr>
<tr>
<td>Turkey</td>
<td>2.9</td>
<td>62.5</td>
</tr>
<tr>
<td>Argentina</td>
<td>2.2</td>
<td>82.1</td>
</tr>
<tr>
<td>Colombia</td>
<td>2.1</td>
<td>79.7</td>
</tr>
<tr>
<td>Brazil</td>
<td>1.9</td>
<td>15.3</td>
</tr>
<tr>
<td>Peru</td>
<td>1.6</td>
<td>89.8</td>
</tr>
<tr>
<td>Korean Republic</td>
<td>1.6</td>
<td>40.9</td>
</tr>
<tr>
<td>Egypt</td>
<td>1.1</td>
<td>26.0</td>
</tr>
<tr>
<td>Chile</td>
<td>1.0</td>
<td>89.2</td>
</tr>
</tbody>
</table>

- Developing-country production as % of global production = 19.7.

Although in the developed world the potato has many industrial and food-processing uses, including starch and alcohol (Smith 1977), potatoes in the developing countries are almost exclusively eaten fresh. Nevertheless, a change in food usage has taken place in many countries and has resulted in a rapid increase in potato production in the tropical world. As recently as 20 or 30 years ago, the potato was restricted to the highland tropics and, elsewhere, was confined to use by privileged economic groups, especially expatriates. Against this background, merchants could afford refrigerated storage, and producers could tolerate exceedingly low yields. This pattern still exists in some areas, but, in many countries, potato is becoming an everyday staple food of the producer. Kenya and highland India are of particular interest, as the potato is becoming quite widely accepted as a subsistence crop as well as a crop for sale at high prices for luxury markets.

To eliminate storage at artificially reduced temperatures, producers have adopted the philosophy of "storage avoidance": spreading production through as large a portion of the year as possible. Another approach currently being recommended by CIP is to store the tubers in the cool highland production areas and transport them to urban centres of demand, etc., which are frequently in the lowlands, as late as possible. For seed potatoes, storing the tubers in simple structures exposed to diffused light, which minimizes sprouting, shows great promise. A major storage problem is the potato tuber moth (Booth and Shaw 1981). In the Andes, potatoes are commonly stored in stacks incorporating layers of a local aromatic plant, "muña," the essential oil of which has a strong repellent effect.
on the tuber moth. Aromatic herbs such as Ocimum in West Africa might have similar effects and contribute to the reduction of losses by potato tuber moth in potato storage.

In the potato's area of origin, for hundreds of years — long before European contact — local inhabitants have been processing the potato into a product known as chuño (Werge 1979). They slice the tubers, expose them to freezing temperatures at night to break down the cellular structure, press them at the same time as exposing them to the sun during the day. This process is only suitable for comparatively limited parts of the tropics where freezing temperatures occur at night.

**COCOYAMS AND OTHER AROIDS**

The total production of the aroid root crops, of which Colocasia and Xanthosoma are by far the most important, is far less than that of yams and cassava or even potato and sweet potato. Nevertheless, they are important in that they are widely distributed. *Colocasia* is well adapted to cultivation under swamp or even flooded conditions, making the use of otherwise useless land possible. Other cultivars, especially of *Xanthosoma*, are adapted to drier upland conditions, although they generally yield less in terms of tonnes per hectare. Under good conditions, cultivars of both genera can be exceedingly high yielding (Coursey 1968b). They are now both of pantropic distribution, *Colocasia* having diffused in cultivation from its origin in Southeast Asia in ancient times and *Xanthosoma* recently moving to most of the areas where *Colocasia* is grown. Outside Hawaii, where the cultivation of *Colocasia* is highly organized, these crops are essentially backyard crops. Over the last few years, a trade in *Colocasia* (more than $2.0 \times 10^3$ t annually), has developed from Fiji, Tonga, and especially Samoa, to support Polynesian immigrants in New Zealand (Watson 1979). Similarly, substantial quantities ($1.0 \times 10^3$ t annually), mainly dasheen — *C. esculenta* var. *esculenta* — are exported from the Caribbean to the United Kingdom where, again, they are used mainly by immigrants (Bell and Coursey 1970).

Harvested when required, cocoyams are seldom stored, and the small amount of information about their storage behaviour is conflicting. In Polynesia, *Colocasia* cultivars (known as taro or dalo) are sometimes fermented as a paste in pits in the ground, which it is claimed can be kept for several months; a similar technique is used for pulp made from breadfruit. I do not know the details of the process, which is said to be dying out with the introduction of imported foods. A study of the microbiology involved is desirable. In Africa and those parts of Asia where the crop is important, many varieties are known, and there are strong local preferences for one or another. In Africa in particular, *Xanthosoma* is tending to take over from *Colocasia*; the reason being given is that the former can yield a culinary product not too dissimilar from yam fufu. The fact that it is used quite widely as a shelter crop for young cocoa has contributed substantially to the spread of *Xanthosoma* in West Africa. The corms or cormels are usually eaten boiled, mashed, or sometimes pounded, frequently mixed with other staples, such as yam or plantain. They are grated and incorporated into soups or stews. The leaves of several cultivars are consumed, especially in the Caribbean and Latin America, as constituents of either soups or salads. One species, *X. brasiliense*, is grown entirely for its leaves for salad use rather than for its starchy corms.

No discussion of the use of the aroids as food — virtually their only use — would be complete without mention of their irritancy or "scratchiness." Although they vary in this quality, many cultivars have such a high degree of irritancy as to be unpalatable unless thoroughly cooked. Some individuals, however, are able to consume more irritant cultivars than are others. Many animals are also sensitive to the irritant. Most studies (Coursey 1968b) have attributed the quality to the presence of needle-shaped crystals or raphides of calcium oxalate, which can be detected microscopically in the tissues of the plant. Without doubt, these contribute to the effect, but recent research suggests that, in common with several other aroids, the cells that contain the raphides contain a toxic substance that irritates the wounds caused by the raphides. The enormous variation between cultivars suggests that breeding programs could eliminate or minimize the problem.

Some cocoyam corms, cormels, and leaves are fed to household stock, such as goats, in many parts of the tropics, but no organized industry has been built for animal feeds. The whole plant might well prove suitable for ensilage as animal feed (Coursey and Halliday 1975), and some experimentation, mainly with *Colocasia*, has been undertaken in Hawaii (Steinke et al. 1982; Wang and Nagarajan 1983). The work was initially conducted with the leaves, which are often wasted in Polynesian agricultural systems, but some ex-
Experiments on whole-plant ensilage were also conducted. Both types of silage proved entirely acceptable to pigs and ruminants. In view of the high yields that can be obtained with certain aroid cultivars, this source of animal feed appears well worth investigating in other tropical countries.

*Colocasia* starch grains are exceedingly small (Rasper 1981) so they may be suitable for the manufacture of biodegradable plastics, in which the size of starch particles is directly related to speed of biological degradation (Griffin 1979).

The remaining aroid genera, *Alocasia, Cyrtosperma, Amorphophallus,* and *Anchomanes,* are used only as local foods in their area of production. An exception outside the developing world is that of *Amorphophallus rivieri,* which stores its carbohydrate reserves as mannan instead of starch and is utilized in Japan for commercial production of mannans and mannose. If the tropical species also store their carbohydrate in this form, industrial utilization of these crops, which are particularly important in south India and in Indonesia, should be possible.

Further information on aroid utilization has been published elsewhere (Plucknett 1979; IFS 1982), and a multiauthor monograph on *Colocasia,* edited by Wang, has just been released.

**Conclusions**

As far as can reasonably be predicted, the major tropical root crops will continue for several decades to occupy essentially the same position in agricultural economies as they do today; they will primarily remain a source of human food. Use of the cheaper root crops, such as cassava and sweet potato, as animal feed will probably increase, although the opportunities for export of dried products show little capacity for improvement and may even decline. The decline will probably be more than counterbalanced by increased use, especially of cassava, in producer countries. The use of silage from aroids for animal feed may also have a future.

Industrial utilization, mainly for starch, may increase, especially in countries where there is a local demand, but the position of cassava starch on international markets is not strong. Specialty uses for some root-crop starches are a possibility.

The use of cassava or sweet potato for fermentation of industrial alcohol is not likely to increase unless petroleum costs rise substantially.

In the long term, mechanized production of "instant" reconstitutable products will be established at the industrial level, especially for yam.