TROPICAL ROOT AND TUBER CROPS

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Summary

The tropical root and tuber crops (cassava, sweet potato, yams and aroids) are of utmost importance for the world food security. They are major sources of energy in developing countries with fast population growth and high urbanization rates. They are the staple food for hundreds of millions of poor people. These crops are expected to contribute significantly to the increased income generation and nutritional well-being of people in the tropics in the next decades. However, low productivity, limited added value and

poor access to markets due to their perishable nature, are major constraints which are still insufficiently addressed. This paper presents an overview of the history, crop description, breeding aspects, agronomy and uses of these tropical root crops.

1. Introduction

Root and tuber crops (cassava, sweet potato, yams and aroids) are the second group of cultivated species, after cereals, in tropical countries. They are produced with very low inputs, are consumed by the poorest, contribute significantly to food security and are also used for animal feed or as raw material for processing industries. These species belong to different botanical families but, for the purpose of scientific research, are grouped together because they are vegetatively propagated, produce underground food, and are bulky and perishable (Table 1).

Their contribution to the world food security, in particular in developing countries, is essential. Their importance in the future might come from either their potential to substitute cereals, their use as a source of new starches, or just as a basis for yet undefined processed products. However, a number of their characteristics hinder greater industrial exploitation, i.e. they have no uniform shape, making mechanical peeling difficult; skin and flesh, color and texture do vary; and there is limited data on starch content and composition.

Characteristics	**Cassava** *Manihot esculenta* **Euphorbiaceae**	**Sweet potato** *Ipomoea batatas* **Convolvulaceae**	**Yams** *Dioscorea* **spp. Dioscoreaceae**	**Aroids** *Colocasia esculenta* **and** *Xanthosoma sagittifolium* **Araceae**
World production in 2007 (millions tons)*	226	124	51	13
World cultivated area (millions ha)	18.6	9.0	4.6	1.9
World average yield (fresh tons/ ha)	12.2	13.7	11.2	6.7
Yield potential (fresh tons/ ha)	90	120	110	110
Planting material (propagule)	Stems	Vine cuttings	Tubers	Corms, suckers
Growth period (months)	8 - 36	3 – 6	8 – 36	6 - 16
Optimal rainfall (mm)	1000 - 1500	750 – 1000	1200 - 1500	2500-3500
Optimal temperature (°C)	25 - 30	20 – 25	30	20 - 35
Drought resistant	Yes	Yes	Yes	No
Waterlogged tolerant	No	No	No	Yes
Shade tolerant	No	No	No	Yes
Soil fertility requirements	Low	Low	High	High
Seasonality of crop cycle	No	Yes	Yes	No
In-ground storage life	Long	Moderate	Moderate	Long
Postharvest storage life	Very short	Short	Long	Moderate
Leaves used for human consumption	Yes	Yes, fairly common in West Africa and East Asia	No	Yes
Leaves used for animal feed	Yes	Yes	No	Yes

Dry matter (% fresh weight, FW)	30 - 40	20 – 35	20 – 40	20- 30
Starch (% FW)	27 - 37	18 – 28	20 – 25	15 - 25
Starch grain (in microns)	5 - 50	2 – 40	1 – 70	1 - 6
Amylose (% starch)	15 - 30	8 – 32	10 – 30	3 - 45
Gelatinization temp. (°C)	49 - 73	58 – 65	69 – 88	68 - 75
Total sugars (% FW)	0.5 – 2.5	1.5 – 5.0	0.5 – 2.0	2.0 – 3.0
Proteins (% FW)	0.5 – 2.0	1.0 – 3.0	2.0 – 4.0	1.5 – 3.0
Fibers (% FW)	1.0	1.0	0.6	0.5 – 3.0
Vitamin A (µg/ 100g/ FW)	17	900	117	0 - 42
Vitamin C (mg/ 100g/ FW)	50	35	25	10
Minerals (% FW)	0.5 – 1.5	1.0	0.5 – 1.0	0.5 – 1.5
Energy (kj/100g/FW)	600	500	440	400
Anti-nutritional compounds	Cyanogens	Trypsin inhibitors	Alkaloids, Tannins	Oxalate crystals

* From Bradbury and Holloway (1988).

Table 1**.** Characteristics of the tropical root and tuber crops (Lebot, 2009).

Nevertheless, these species share a number of common agro-biological traits. Cultivars are annual; their flowering ability is erratic; they have variable ploidy levels, but are predominantly allogamous and highly heterozygous. As for most vegetatively propagated species, breeding is based on selection of numerous hybrids evaluated for a few traits of interest. Parents selected on their individual value are intercrossed and visual appraisal is used to discard undesirable genotypes. This slow process is conducted on research stations but genotype x environment interactions are significant.

The geographical distribution of clonal material is constrained by its low multiplication rate, the vast number of poor smallholders growing them, their isolation, the absence of a commercial seed industry and strict international quarantine regulations. In most developing countries publicly supported commodity development programs for tropical roots and tubers are under funded or exist in name only. Hence, smallholders that grow these crops are left to manage their germplasm and the health status of their planting material largely on their own. Under such circumstances, when pests and other diseases strike, consequences can be severe. Because of biological constraints, when cultivation intensifies these crops become vulnerable to pests and pathogens. Their clonal nature accelerates the spread of viruses through infected planting material. Traditionally, risk management is controlled by mixing together different varieties or intercrops, thereby creating within sustainable agro-forestry systems, obstacles to pest and pathogens expansion.

2. Cassava

Cassava (*Manihot esculenta* Crantz, Euphorbiaceae, Dicotyledon) is the sixth most important crop (after wheat, rice, maize, potato and barley) in the world. It contributes consistently to food security because its mature edible roots can be stored in the ground for up to three years. It represents a household food bank that can be drawn upon when adverse climatic conditions limit the production of other foods. The variety of dishes made from the roots and the nutritious fresh leaves are reasons why cassava cultivation is expanding throughout the Tropics.

2.1. History

Traditional ovens used to cook pancakes made of cassava have been dated 1200 BC in northern Colombia and other archaeological sites dated 2700 BC near Lake Maracaïbo in Venezuela. Spontaneous wild forms have been reported from the central Brazilian state of Goiás where a possible ancestor of cassava (*M. esculenta* ssp. *flabellifolia*) still thrives; it is believed that this region is the centre of domestication. Numerous other reports refer to the natural hybridization of wild *Manihot* species, between wild species, and between them and cultivars in South America. Domestication could therefore have occurred in different places within this vast region.

Cassava was first introduced into Africa by Portuguese traders around 1550. Early dissemination of cassava through pre-colonial Congo was probably carried out solely by Africans. When Stanley entered the Central African interior in 1877, the crop was already established. In the late 19^{th} and 20^{th} centuries, colonial administrators encouraged its cultivation. Around the Indian Ocean, cassava was introduced in Réunion and Mauritius by the French in 1738, and from there the crop spread over Madagascar where it is cultivated on the Central High Plateaus since 1875.

In India, the Portuguese settlers introduced cassava to Goa during the 16^{th} century, and it seems that its cultivation really expanded in South East Asia during the 19^{th} century. In the Pacific, cassava was introduced by the French to New Caledonia in 1850 and it reached Queensland, Australia, at the beginning of the 20th century. Nowadays, it is the staple crop for most people living in the many islands of the South Pacific.

To date the main cassava producing countries are Nigeria, Thailand and Brazil (Table 2). The highest yields (more than 16 t/ha) are obtained in Asia. In Africa average yields are low (less than 12 t/ha), mainly because the crop is almost exclusively grown by smallholders in a slash and burn system without fertilizer application.

Region	**Country**	**Production (000t.)**	**Area (000ha)**	**Average yield (t/ha)**
Africa	Nigeria	45,721	3810	12.0
	Congo (*ex* Zaire)	14,974	1846	8.1
	Mozambique	11,458	1105	10.4
Asia	Thailand	22,584	1071	21.1
	Indonesia	19,928	1223	16.9
	Vietnam	7714	475	16.2
America	Brazil	26,713	1902	14.0
	Paraguay	4800	300	16.0

Table 2. Major cassava producing countries in the world (www.fao.org, 2009)

2.2. Plant Description

Cassava is traditionally planted by smallholders but large-scale commercial plantings are established in response to industrial processors in demand for starch. Roots are the main storage organ. When the plant develops only a few fibrous roots become tuberous while most of the others continue their function of nutrient absorption (Figure 1).

The starchy root is circular in cross section and is thicker at its proximal end. The distal portion tapers slowly and beyond the tuberous section, the root extends as a normal root. The tuberous root is connected to the base of the plant by a woody section called the neck. The internal section of a starchy root is composed of three parts:

- The bark (also called periderm),
- The peel layer (also called phelloderm, cortex or secondary skin) which is only 1-2 mm thick and is usually white, pinkish or brownish,
- And the central portion representing the bulk of the root, the parenchyma.

The flesh consists mostly of cells with large amounts of stored starch and is the edible portion. There are no eyes or buds on the root surface and therefore, cassava roots cannot be used as a means of vegetative propagation.

The cassava plant produces cyanide (HCN) in toxic quantities. It occurs as two related cyanogenic glucosides (CG): linamarin (93% of the total cyanide content) and lotaustralin. At high concentrations, cyanide can cause death; for humans, the lethal dose of HCN ranges between 0.5 and 3.5 mg/kg of body weight. Both roots and leaves contain CGs. All varieties contain CGs and cultivars are classified as “sweet” (less than 100 mg of total CGs per kg of peeled fresh roots) and “bitter” (more than 100 mg of CGs).

Figure 1. Cassava roots.

2.3. Breeding

All wild *Manihot* species have a chromosome number of $2n = 36$ and behave like diploids at meiosis. Cassava is generally considered a normal diploid (with $2n = 36$ chromosomes), but natural triploids occur and are selected by farmers and cultivated.

Breeding objectives vary from one country to another and depend on the final use of cassava. For the industry, yield improvement (in terms of starch and dry matter) per unit area and time is the most important objective, while for the subsistence cropping, chemotype and yield stability are essential.

The ideal breed should have the following characteristics: only one stem per cutting with little or no branching, a high ratio roots/stems, short internodes and total height of the plant less than 2 m, approximately eight short and compact tuberous roots, easy to harvest and to peel, and reduced post harvest deterioration. Yield stability is associated with tolerance or resistance to local pests and diseases.

The selection process is equivalent to mass recurrent selection, and great numbers of hybrids have to be screened. The process is based on the capture of additive effects and is particularly efficient for traits with high heritability when there is a broad genetic base. It is thought that cassava improvement could greatly benefit from the introduction of inbreeding into the selection process. The production of homozygous lines through tissue culture techniques for the purpose of capturing hybrid vigor appears promising. Increased homozygosity could result in a decrease of the genetic load and double haploids are expected to produce better hybrids. The use of transgenic technologies to incorporate desired traits into the best cultivars is also attractive because they allow rapid gene transfer from one cultivar to another or from a wild species to a cultivar, bypassing problems related to heterozygosity and inbreeding.

Somatic embryos can be produced and whole plants can be recovered from immature leaf lobe explants. These embryos are used as the target for transgene insertion.

2.4. Agronomy

Cassava is a perennial shrub which can grow for years, alternating periods of vegetative growth and periods of storage in the roots, with eventually some periods of dormancy (if temperatures are low). In cultivation, however, it is treated as an annual. During the growth, there are five distinct phases: sprouting, leaf and root system development, canopy establishment, high carbohydrates translocation, and dormancy.

Temperature has considerable effects on cassava growth. It affects sprouting, leaf formation, leaf size and, therefore, plant growth in general. Cassava growth is favorable under temperatures ranging from 25 to 29° C, but it can tolerate temperatures as low as 12° C and as high as 40° C. The plant responds to water deficiency by rapidly reducing its evaporating leaf area by partially closing the stomata. This increases the efficiency of water use. When severe, a drought period can induce a diminution of the yield depending on the duration of the water deficit and its position in the growth cycle. The critical period is between 30 and 150 days after planting which corresponds to the root initiation phase. During that period, a water deficit of at least two months can cause a decrease in root yield from 30 to 60%.

Cassava can be successfully cultivated in areas with annual rainfall between 1000 and 3000 mm but it can tolerate lower rainfall if well distributed. The most favorable conditions seem to be in climates with 1500-2000 mm/year and maximum solar radiation. In areas with no marked seasonality, cassava can be planted all year round.

Pests and diseases vary greatly between the three major producing regions, indicating that severe quarantine measures should prevent their introduction from the Americas to Africa, Asia and the Pacific. Not less than 200 different species have been reported. In South America, arthropod pests feed on cassava leaves and drastically reduce its productivity. In Asia, none of the major American pests has become endemic and native arthropods are not causing serious crop damages. In Africa, *cassava mosaic disease* (CMD) and *cassava brown streak disease* (CBSD) are the major constraints to production. In India, a disease similar to CMD is also a constraint in the southern part of the subcontinent. Bacterial blight (induced by *Xanthomonas axonopodis* pv. *manihotis*) is present in Asia, Africa and Latin America and is also a major production constraint.

Cassava bacterial blight (CBB) is one of the most serious diseases affecting cassava and is caused by *Xanthomonas campestris* pv. *manihotis*. It is found on cassava and related species. It has caused severe epidemics following its introduction into Africa; the disease is minor in Asia. In the Congo, the introduction of the disease has led to total loss of planting material but after the introduction of resistant varieties, the disease was contained.

The brown leaf spot caused by *Cercospora henningsii* is one of the most common diseases in cassava. This disease has a worldwide distribution and occurs almost always in plantings located in areas with high temperatures. The optimum conditions for spore production are when free water on the surface of the leaves reaches a temperature between 25 and 32° C. Older leaves are more susceptible than younger ones.

Scientists have isolated 17 different viruses to date and it is very likely that new ones will be identified soon. C*assava common mosaic virus*, the *cassava vein mosaic virus* and the *cassava frogskin virus* are the three most important viruses in terms of economic losses.

2.5. Use

Cassava roots are a good source of energy, an average source of minerals and vitamins and a poor source of proteins. Cassava leaves are rich in calcium and a good supplier of proteins. The use of edible cassava leaves as a green vegetable is popular in Africa and Madagascar. Cassava leaves vary considerably in terms of moisture, vitamin C and iron contents. The cyanide content of leaves is not significantly different from that of roots. There is considerable potential for enhancing the nutritional value of cassava through breeding. For example, reports on the variability for carotene content of cassava germplasm indicate that the intensity of root color is highly correlated with carotene concentration. The carotene content in the fresh root varies from less than 0.77 mg/100 g to 4.69 mg/100g dry root.

For the industry, the moisture content of the dried chips has to be reduced to 14% maximum. Standard specifications are 65% minimum for starch, 5% maximum for raw fiber and 3% maximum for powder or flour. Industrial processing includes: peeling, grating, starch extraction, fermentation, pressing, frying and toasting, pounding and changing the texture, drying, and grinding, milling and sieving. Major constraints being faced by processors include: the high cost of roots, appropriate and affordable equipment, poor product quality, absence of producers' and processors' organizations and high energy costs.

Industrial processing aims mostly at extracting cassava starch. Starch represents between 70 and 85% of the root DM and is easily extractable because cassava roots contain low levels of fat and protein. The fresh roots are washed, peeled with knives, grated through a perforated steel plate. The pulp is then washed with water by hand and the fiber is squeezed out while the starchy milk is collected into a container where it settles. The supernatant is removed and the moist starch is dried on trays or mats. In some places, the starchy milk is trapped in clothes and hung so that it drains before it is sun-dried. Most starch processing is done by small companies using simple machines designed locally. In many cases, however, electricity is used.

The simplest way of preserving cassava is to store it in the ground until the crop is harvested. Different genotypes have different optimum limits of storage beyond which weight loss or quality deterioration takes place. With the rapid spread of sweet type cultivars, cassava roots are now increasingly consumed boiled directly after harvest. Throughout West Africa, *fufu* is made by steaming or boiling peeled roots and pounding them into sticky dough which is eaten with soups and sauces. In the Philippines, fresh cassava roots are squeezed and once the juice is expelled, the pulp is made into pellets called *landang*, or 'cassava rice'. In Vanuatu, the fresh roots are grounded into a paste and steamed cooked to produce *laplap*, a pudding.

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Biographical Sketch

Vincent Lebot is a geneticist at CIRAD (*Centre de Coopération Internationale en Recherche Agronomique pour le Développement*) in Port Vila, Vanuatu. He obtained his Ph.D. in Plant Physiology from the University of Montpellier in France in 1988, has served as a geneticist at CIRAD in New Caledonia, Madagascar and as a research fellow at the University of Hawaii and the University of Montpellier. He is now based in Vanuatu where he is breeding root crops. He is the scientific coordinator of TANSAO (Taro Network for South East Asia and Oceania) and SPYN (the South Pacific Yam Network). He has spent the last thirty years studying various root and tuber crops species, their agrobiodiversity and breeding potential. His research focus is on the underground organs quality improvement via conventional genetic improvement and cross breeding. In 2003 he received the David Fairchild Medal for Plant Exploration in Miami, Florida. He has published numerous papers on root crops and co-authored others with students. He has also published several books on underexploited tropical plants.