CASSAVA
Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
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CASSAVA: Post-harvest Operations

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1.Introduction

1.1 Overview

Cassava (*Manihot esculenta* Crantz) is the fourth supplier of dietary energy in the tropics (after rice, sugar and maize) and the ninth world-wide. Its cultivation and processing provide household food security, income and employment opportunities for 500 million people in Africa, Asia and the Americas. The crop is tolerant of low soil fertility, drought and most pest and diseases with no critical date of harvest. These attributes have made cassava into a crop of primary importance for the food security of farmers living in fragile ecosystems and socially unstable environments. However, in communities having access to markets, cassava can become a source of income and employment for both men and women.

It is estimated that 164 million tons of cassava roots were produced in 1995 (FAOSTAT, 1997). Slightly more than half of that amount was produced in Africa, and the rest in Asia and Latin America. The major producing countries are Nigeria, Brazil, Thailand, D.R. Congo, and Indonesia, which together account for two thirds of the world production (See Table 1).

Cassava is a staple food in tropical countries and provides more than 10 percent of the daily dietary caloric intake to about 300 million people in 15 African countries and in Paraguay (See Table 2). In the Democratic Republic of Congo, cassava is estimated to provide more than 1000 kcal/day to over 40 million people. However, in Thailand, the third world largest producer, cassava contributes less than 1 percent to the dietary calories: about 90 percent of total production are exported mainly to Europe; the remaining amount is mostly used in industrial applications.

Despite its importance, cassava is mostly grown by small farmers on small plots of land. Urban consumers and factories obtain their cassava from rural areas where it is grown. Cassava is usually processed immediately after it is taken from the ground because it is highly perishable. Spoiling starts within 48 to 72 hours after harvest.

A mature cassava root (hereafter referred to as 'root') may range in length from 15 to 100 cm and weigh 0.5 to 2.5 kg. Circular in cross-section, it is usually fattest at the proximal end and tapers slightly towards the distal portion. It is connected to the stem by a short woody neck and ends in a tail similar to a regular fibrous root (See Figure 1).

The central pith constitutes the bulk of the root and is primarily a storage parenchyma harbouring a multitude of xylem vessels. A thin layer of cambium mainly responsible for the root expansion surrounds the storage parenchyma whose cells accumulate large starch granules. At the centre of the parenchymal tissue, the primary xylem is organised in a fibrous vascular bundle.

Table 1. Production of cassava in Africa, Asia and the Americas, and in selected countries in 1995

		Production (million tons)	Yield (ton/ha)	Area Harvested (thousand ha)
World		165.3	10.1	16,240
Africa		84.4	8.4	9,880
	Nigeria	31.4	10.7	2,940
	Congo, D.R.	18.0	8.3	2,100
	Ghana	6.9	13.3	520
	Tanzania	6.0	10.2	585
	Mozambique	4.2	4.2	986
	Uganda	3.0	7.5	350
	Madagascar	2.4	7.2	336
	Angola	1.7	4.1	410
	Côte d'Ivoire	1.6	5.0	610
	Cameroon	1.3	16.3	80
	Benin	1.1	8.1	141
Asia		48.5	13.3	3,634
	Thailand	18.2	14.0	1,297
	Indonesia	15.4	12.2	1,266
	India	6.0	23.5	255
	China	3.5	15.2	230
	Viet Nam	2.5	8.9	281
	Philippines	2.0	8.7	215
South America		31.4	12.5	2,512
	Brazil	25.5	12.9	1,981
	Paraguay	2.6	14.9	175
	Colombia	1.9	9.7	198
North and Central America (Mexico and the Caribbean)		1.0	5.1	198

Source: FAOSTAT, 1997

Table 2. Contribution of cassava to dietary calories in selected countries, 1992-1994

Country	Amount per person (kcal/day)	Percentage of total dietary energy (%)	Population (million)
Congo D.R.	1099	54.1	41.241
Mozambique	608	36.1	15.121
Congo R.	726	33.2	2.443
Angola	502	28.6	10.279
Ghana	625	26.5	16.450
Central Africa R.	485	24.8	3.156
Tanzania	452	22.0	28.023
Benin	456	19.6	5.087
Madagascar	339	16.5	13.858
Togo	324	15.8	3.886
Nigeria	405	15.6	105.287
Uganda	302	14.0	19.941
Paraguay	329	13.9	4.701
Cameroon	279	12.9	12.526
Côte d'Ivoire	300	12.7	13.319
Gabon	271	11.0	1.248
Burundi	169	9.4	6.027
Guinea	204	8.7	6.308
Chad	108	5.9	6.013
Sierra Leone	107	5.7	4.298
Indonesia	127	4.9	191.676
Kenya	86	4.5	26.388
Brazil	111	4.0	156.483
Vietnam	79	3.4	71.331
Colombia	87	3.3	33.958
Fiji	85	2.8	0.758
Philippines	55	2.3	64.805
Cuba	52	2.1	10.874

Source: FAO, 1996. Food Balance Sheets, 1992-1994.

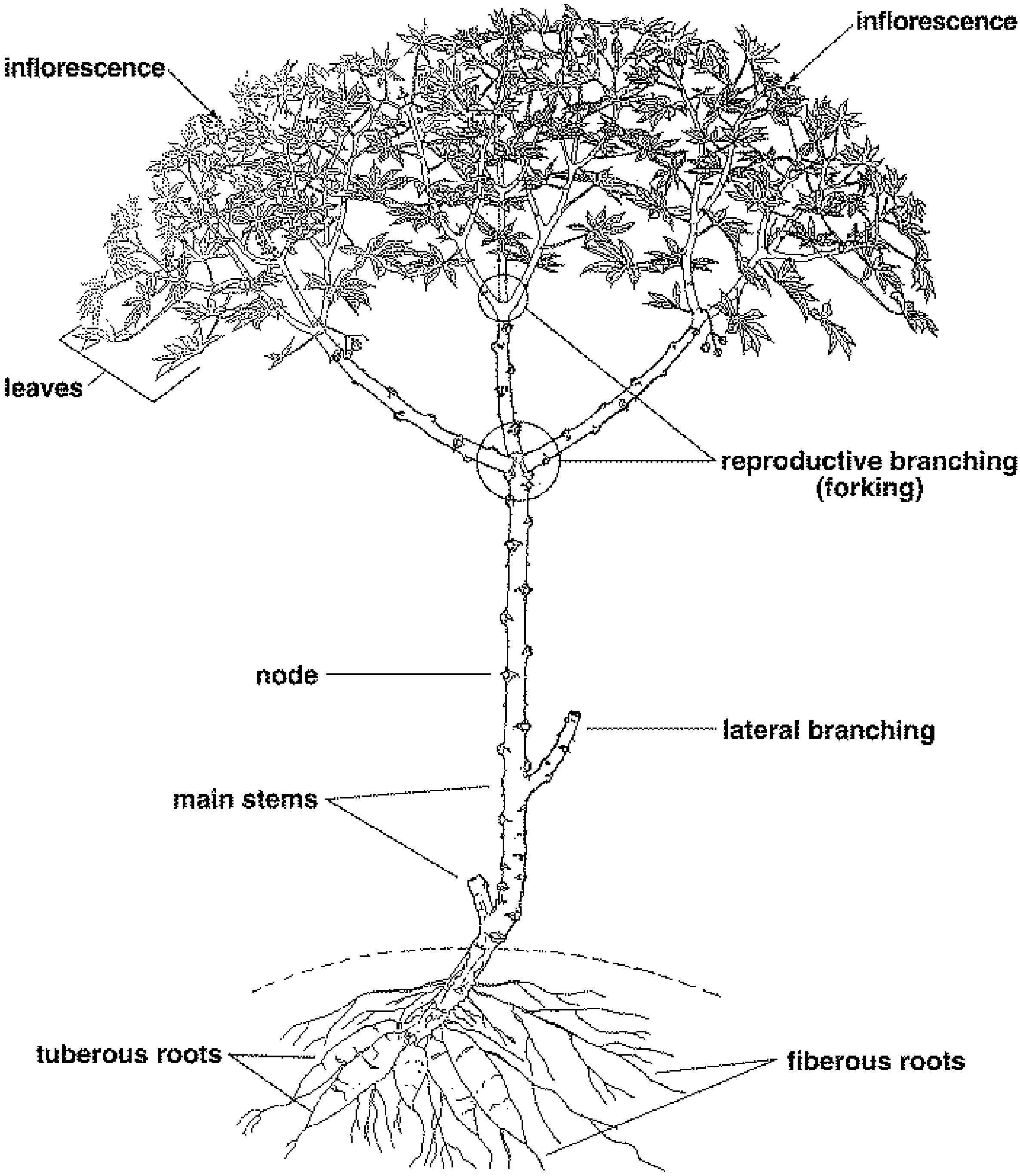


Figure 1: Diagram of a cassava plant

A transversal section of the root (See Figure 2) reveals three distinct parts: the peel, the central pith, and the vascular bundle. The peel is usually not considered suitable for human consumption, but can be used for feeding pigs. The central pith is the edible portion; it constitutes the bulk of the root and is primarily a storage parenchyma harbouring a multitude of xylem vessels. A thin layer of cambium mainly responsible for the root expansion surrounds the storage parenchyma whose cells accumulate large starch granules. At the centre of the parenchymal tissue, the primary xylem is organised in a fibrous vascular bundle.

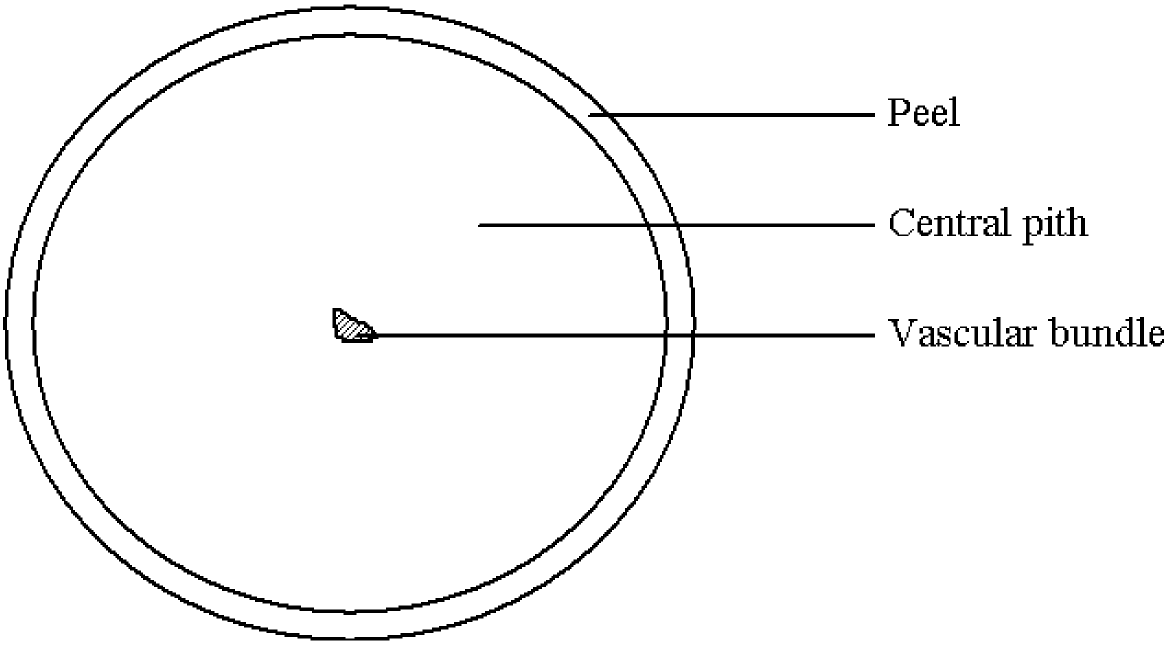


Figure 2: Transversal section of a cassava root.

Although the tuberous roots of cassava constitute the economically important part of the plant, the younger leaves are also consumed as vegetable in many countries. In countries such as the Democratic Republic of the Congo, Tanzania, Sierra Leone, Liberia and Guinea, cassava leaves are a major component of the diet; in other countries they are less preferred and are only consumed in times of food shortage.

In Africa, peeling of cassava roots is common and is labour-intensive. However, for *farinha* production in Brazil, cultivars such as «Branca de Santa Catarina» with a white peel have been selected so that they can be processed without removing the peel, thus considerably reducing the labour cost.

Cassava roots mainly contain carbohydrates, of which 80% is starch. The levels of protein (1-2%) and fat (less than 1%) are not nutritionally significant. However, the approximate composition (See Table 3) and micronutrient content (See Table 4) of the leaves compare favourably well with other foods such as soybean and maize grain, and amaranth leaves (West et al., 1988).

Table 3. Approximate composition (% of fresh weight) of cassava leaf, amaranth leaf, soybean and yellow maize. (In brackets the percentage on dry matter basis.)

Moisture		Protein	Fat	Carbohydrates	Fibre	Ash
Cassava leaf	72.0	7.0 (25.0)	1.0 (3.6)	14.0 (50.0)	4.0 (14.3)	2.0 (7.1)
Amaranth leaf	84.0	4.6 (28.8)	0.2 (1.3)	7.0 (43.8)	1.8 (11.3)	2.9 (18.1)
Soybean	11.0	34.0 (38.2)	18.0 (20.2)	29.0 (32.6)	4.7 (5.3)	5.0 (5.6)
Maize (yellow)	10.0	10.0 (11.1)	4.8 (5.3)	72.0 (80.0)	2.0 (2.2)	1.2 (1.3)

Source: West et al., 1988.

Table 4. Mineral and vitamin content of 100 g of cassava leaf, amaranth leaf, soybean and yellow maize

	Ca	Fe	ß-carotene	Thiamin	Riboflavin	Niacin	Vit. C
	(mg)	(mg)	(µg)	(mg)	(mg)	(mg)	(mg)
Cassava leaf	300	7.6	3,000	0.25	0.60	2.4	310
Amaranth leaf	410	8.9	2,300	0.05	0.42	1.2	50
Soybean	185	6.1	28	0.71	0.25	2.0	0
Maize (yellow)	13	4.9	125	0.32	0.12	1.7	4

Source: West et al., 1988.

The nutritional value of fresh foods that are actually consumed after some kind of processing is only indicative of the potential contribution of these foods to the nutrition of the consumer. The composition of prepared foods should be considered for a better evaluation of the quality of these foods. The literature is scant on this aspect, but it has been shown that most processes to which cassava is submitted in the preparation of food products lead to reductions in protein, vitamin and mineral content (Lancaster *et al.*, 1982).

Protein is reduced by 50 to 87 percent in the preparation of foodstuffs from cassava roots in Cameroon, while vitamin C, niacin and thiamine are almost entirely lost (Favier *et al.*, 1971). Riboflavin, on the other hand, has been found in higher quantities in some fermented cassava products than in fresh cassava roots, and it has been suggested that this vitamin may be synthesised during fermentation (Favier *et al.*, 1971; Watson, 1976).

Data on the loss of nutrients during the preparation of cassava leaves are even more rare. Protein is reduced as in the preparation of cassava roots. Vitamin C is reduced by more than half when the leaves are boiled for 10 minutes (Watson, 1976). The remaining concentration of nutrients does, however, still provide a good contribution to the daily requirements (Lancaster and Brooks, 1983).

Cassava roots should be considered as merely a source of carbohydrates or calories for the diet. Their main advantage is their low cost. Thus, energy requirements can be met at a low cost and a larger proportion of the income can be devoted to other foods and/or needs. This is important on two counts: first, it makes it easier for poor populations for whom cassava is the main staple to afford other items of their diet; and second, it makes much nutritional sense since meeting one's energy requirements has been recognised as a prerequisite for a good utilisation of other elements such as proteins in the diets (FAO/WHO, 1973). It has been recently shown that cassava is a good source of energy and that it interferes very little with the digestion of added protein and fat in weaning diets (Morales and Graham, 1987). A positive effect of cassava on the metabolism of cholesterol in the rat has also been reported (Brydon, 1982). These arguments encourage the utilisation of cassava and call for more research on this crop.

1.2 World Trade

The annual global supply of cassava has increased steadily at a rate of 2.3 percent per year between the 1972-74 and the 1992-94 periods (see Tables 5 and 6) to reach an additional supply of 60 million tons of fresh root equivalent per year. The increase was more pronounced in Africa which averaged a growth rate of 3.4 percent in the same period. Cassava production grew at a rate of 2.6 percent in the 1970s and of 4.2 percent in the 1980s. The main reason for this increase were insufficient alternative food supplies, demographic pressures and failure of other crops during droughts, and in some countries such as Ghana, policies intended to promote cassava and in Nigeria policies to reduce cereal imports.

Between 1985 and 1995, cassava production in Ghana and in Nigeria grew at an annual rate of 11.0 percent and 8.4 percent respectively. This rapid increase was due to both expansions in area cultivated and to increases in yields due to the adoption of high-yielding varieties by cassava farmers. Growth rates were more modest in many countries, and were negatives in Mozambique, Tanzania and Uganda.
In Latin America production of cassava declined at a rate of -1.3 percent per year in the 1970s and had a small annual increase (0.2 percent) in the 1980s. This stagnation was mainly caused by a lack of production incentives. In addition, Brazil, which grows 80 percent of the cassava in the region, was hit by a long drought, which reduced yields. However, there is a wide disparity in cassava yields across Brazil: while average yields stand at 4-8 ton/ha in Northeast Brazil, they jump at 20-28 ton/ha in the southern states of Parana and Sao Paulo. In Colombia, cassava production grew at an average annual rate of 1.6 percent per year. Between 1985 and 1995, the annual increase was actually 3.4 percent. This strong performance in a region where cassava production is declining may be related to policies put in place by the Government of Colombia to provide better access to credit and technical assistance by cassava farmers.
Thailand and Indonesia account for the largest share (75 percent) of cassava produced in Asia. In the 1970s, cassava production grew rapidly (5.1 percent annually) due to both yield increase (2.6 percent) and expansion of cultivated land (2.6 percent). This rapid increase in cassava production was due to a growing demand for cassava pellets and starch for export to countries of the European Union. In Thailand, cassava production went from 1.2 million tons in 1960 to about 23 millions tons in 1990. Between 1965 and 1980, production doubled every five years. Like elsewhere cassava is grown, production is primarily in the hands of small scale producers; but in Thailand, cassava farmers averaged yields exceeding 15 tons per hectare compared to a world average of less than 10 tons per hectare. In the late 1980s and early 1990s, the rate of growth in cassava production has slowed down considerably.

Table 5. Cassava production, yield and cultivated area per region, 1972-1994.

Region	Production (million ton)	Yield (ton/ha)	Area harvested (million ha)
	1972-74 1982-84 1992-94	1972-74 1982-84 1992-94	1972-74 1982-84 1992-94
World	102.2 129.5 162.3	8.2 9.3 9.9	12.4 13.9 16.4
Africa	41.5 54.0 82.1	6.0 7.1 8.2	6.9 7.6 10.0
Americas	32.8 28.9 29.5	12.1 10.8 11.6	2.7 2.7 2.6
Asia	27.8 46.4 50.6	9.8 12.7 13.1	2.8 3.7 3.9

Source: FAOSTAT, 1997

Table 6. Growth rates in cassava production, yield, and area harvested between the periods 1972-1974 and 1982-1984 (indicated as 1973-83) and between the periods 1982-1984 and 1992-1994 (indicated as 1983-93).

Region	Production (percent)		Yield (percent)		Area harvested (percent)	
	1973-83	1983-93	1973-83	1983-93	1973-83	1983-93
World	2.4	2.3	1.3	0.6	1.1	0.3
Africa	2.6	4.2	1.7	1.4	1.0	2.7
Americas	-1.3	0.2	-1.1	0.7	-0.2	-0.5
Asia	5.1	0.9	2.6	0.3	2.6	0.5

.Source: FAOSTAT, 1997

In the late 1980s and early 1990s, the European Union imposed a restrictive quota system. Unable to export all of their production, cassava producers in Thailand have begun looking for alternative markets abroad, but also at home. Strong industry-led economic growth pushed cassava cultivation to marginal lands, leading to a decline in productivity (Henry and Gottret, 1995). In Indonesia, a large proportion of the cassava produced is consumed internally. A strong economy and rising incomes have increased demand for cassava starch. Adoption of high-yielding varieties has contributed to an annual production growth rate of 1.4 percent since the mid-1980s.

1.3 Primary product

Wherever cassava is grown, it is primarily used as food. The exception to this rule is Thailand where 90 percent of the cassava produced is exported and the rest is used in industries. In Africa, close to 90 percent of cassava produced is used as food, with very little used for animal feed and even less for export and industries (See Table 7). Post-harvest losses have been estimated at 9.5 percent. In Asia, over half of the cassava production is used as food. Exports account for 27 percent and come primarily out of Thailand and Indonesia. In Latin America and the Caribbean, cassava is used mainly as food (42 percent) and feed (33 percent). The use of cassava in industry accounts for 10 percent of the production in the Americas, 9 percent in Asia, and 0.1 percent in Africa.

Table 7. Uses of cassava by continent (in percentage of production)

Producing region	Food	Feed	Industry	Export	Waste
Africa	88.7	1.4	0.1	0.1	9.5
Asia	55.3	2.9	8.6	26.9	6.3
Americas	42.4	33.4	9.6	0.1	14.0

Source: FAOSTAT, 1997

Cassava has traditionally played an important role as an irreplaceable food security crop in large parts of the developing world. In addition, cassava has increasingly received attention as a low-cost, high quality raw material for both small and large scale manufacturing of a wide range of processed products for growing national markets and for exports.

Africa

Almost all cassava grown in Africa is for human consumption; 30 percent is consumed after peeling, cleaning and boiling, while 70 percent is processed into a wide variety of food products including dry chips and flour, cooked pastes, roasted or steamed granules, beverages, etc. Both rural and urban peoples use these products as a basic daily source of dietary energy. The diversity of products is matched by a proliferation of common names for these foods: the same name could refer to different food products (e.g. *foofoo* or *fufu* is a different product in Ghana, Nigeria and Congo), while the same food product can have different names in different locations (e.g. *kwanga* or *chikwanghe* in Congo, *bobolo* or *miondo in* Cameroon refer to a similar product).

The most popular product in West Africa is *gari*, a free-flowing, granular, fermented and gelatinised cassava product. Easy to store and fast to cook, gari is a convenient food well suited for a busy urban lifestyle. The processing of cassava into gari is labour intensive and requires the use of machinery particularly for the grinding of the roots into a mash. Women are responsible for virtually all cassava processing activities in Africa (Ugwu and Ay, 1992).

Because cassava roots can remain unharvested in the ground for 2 to 3 years, they often play a crucial role during civil unrest when displaced populations return to their farms. This has been seen in Uganda, Rwanda, Burundi, Angola, Mozambique and Liberia. In other countries such as Tanzania and Malawi, cassava has been the only source of food during severe droughts.

Nevertheless, a recent survey has indicated that cassava does not simply play a food security role: an average of 40 percent of cassava per field is planted purposely for sale (Nweke, 1996). Recently, various industries have begun using cassava as low cost commodity to substitute expensive imports of starchy cereals.

Cassava production in Africa has increased steadily in the last thirty years and is the only crop, along with yams, to have kept up with the rate of growth of the population. In Nigeria and in Ghana where the increase in production has been spectacular, the use of cassava by local industries and for export is beginning to expand. Biscuit factories are mixing cassava flour and wheat flour in the production of biscuits, starch is being produced industrially, and one factory has successfully switched from the use of molasses to the use of cassava flour in the production of ethanol. Most of the products are consumed within the countries in which they are produced. However, there is a small but growing export trade in dried cassava chips and other industrial products.

Americas

In the Americas cassava is slowly evolving from a traditional staple to a market oriented inexpensive raw material for the manufacture of human, livestock and industrial products that have more elastic markets than fresh cassava. Consumption of fresh cassava is decreasing in urban areas, but the demand for fresh cassava remains high in low-income groups. *Farinha,* a typically Brazilian product, remains a traditional favourite. Fermented starch (sour starch, *polvilho azedo*), with its bread-making properties is finding new uses in the food industry and in urban fast-food outlets.

Small-scale cassava chip and drying plants are being built in Colombia, Brazil, Ecuador and Panama. Small and medium scale starch industries are used by resource poor farmers to generate income. There is some evidence that the scale of the starch industry is increasing, particularly in southern Brazil. The production of sour starch (a naturally fermented product that acquires the ability to rise like wheat dough during baking) is also increasing in Colombia and Brazil due to new product applications with growing demand such as snack foods and bakery products (Hershey and Henry, 1997).

Asia

Since the 1960s, Asian countries, especially Thailand and Indonesia, have grown cassava for processing into value-added export products, offering Asian cassava farmers some stable source of income. Thailand, Asia's largest cassava producer exports nearly 90 percent of its production mainly as chips and to a lesser extent as starch (Maneepun, 1996). In Indonesia, about half of the cassava produced is for local consumption in fresh or dry forms. The rest is used in food and non-food industries or exported as chips. Currently, the cassava industry in these countries is facing shrinking markets for the export of cassava chips and is shifting towards modified starches and other high added-value chemicals. In contrast, the Philippines and Vietnam grow cassava mainly for their domestic market. In the Philippines, cassava is divided almost equally into food, feed and industrial uses. Only 12 percent of the cassava production in Vietnam are consumed as food, mainly as boiled roots. About 60 percent of the production is processed into cassava flour, mainly for the animal feed industry, while the starch industry accounts for 16 percent of the production (Dang Thanh Ha et al., 1996). China is the fourth largest cassava producer in Asia. In the early 1950s , cassava was mainly used as food; however, in the 1990s industrial uses such as the production of starch and monosodium glutamate constitute the main modes of cassava utilisation (Fang, 1992; Shu-Ren, 1996). Some new industrial products such as ethanol, glucose and fructose are gaining in importance.

Typical cassava foods

It has already been mentioned that cassava can be boiled and consumed as a vegetable. More often than not, the various processing steps described earlier are combined in differing sequences to produce foods typical to specific areas. Sequences may have similar initial steps and then diverge, resulting in very different end products and, conversely, very different processes can lead to similar products. To complicate the matter further, similar products may have different names, while a common name may be applied to different products. There is a myriad of cassava-based food products found all over the world and it would be impossible to mention all of them here. A general review has been compiled by Lancaster *et al.* (1982). Jones (1959) has reviewed the foods made from cassava in Africa. Several authors have reviewed the different uses of cassava foods in individual countries (Favier *et al.*, 1971; Etejere and Bhat, 1985; Nkiere, 1984).

Casabe or 'cassava' bread

Cassava bread is the main staple in the diet of many people in the Amazon Basin and the Caribbean basin, especially in Guyana, Surinam, and Venezuela. It is prepared by reducing cassava into a pulp and spreading the pulp on a hot clay or stone griddle to make a thin and circular cake toasted on both sides. The cake, which may reach 1 m in diameter, is eaten after dipping pieces of it in a stew. Different types of ingredients such as groundnuts can be added to cassava pulp in the making of the cake. The cakes are usually prepared daily for consumption, but they can be sun-dried for several days in order to withstand several months of storage.

Farinha

Cassava pulp is obtained from fresh roots by grating or crushing. The wet pulp is squeezed to remove the excess of water. Various kinds of devices are used for this purpose. The best known and most sophisticated is called *tipiti*; it is a long cylindrical basket constructed by diagonal weaving so that it can be stretched lengthwise at the same time compressing its content. As the basket is stretched, its diameter decreases, the juice is squeezed out and drips along the basket to be collected below if needed. The de-watered pulp is stirred on a hot griddle, taking care to avoid the formation of lumps. The dry granules obtained, known as *farinha seca* or *farinha de mandioca* can be kept for a long time. In Brazil, *farinha* is usually sprinkled on top of other foods to enhance their texture and taste. *Farinha* is produced in small-scale home factories using family labour, or in small-to-medium scale fully mechanised factories with a daily output of 10 to 50 tons of *farinha*. This product is widely commercialised in Brazil where it comes in two grades depending on the particle size of farinha granules: *farinha fina* for a product with very small granules, and *farinha grossa* for a product with larger granules. It should be noted here that, very often, the word farinha is translated as 'flour'; however, given the particle size distribution of farinha, it should be classified as a granular product rather than as flour. A similar product in Trinidad and Tobago is called *farine,* adding to the confusion since this is the French word for flour.

A different type of product known as *farinha d'agua* , found mainly in Northeast Brazil, is made by first soaking peeled or unpeeled cassava roots and allowing them to ferment for 3 to 8 days, or sometimes even longer. During this time fermentation develops and the roots soften. When the roots are removed from the water, the peel is removed if necessary, and a pulp is made, de-watered, and dried like for *farinha seca.* The flour produced in this case has different colour, texture and taste.

Gari

Gari is the most popular cassava product in West Africa. Its preparation is similar to the Brazilian *farinha*. The differences start at the de-watering step. For making *gari*, the wet pulp is placed in cloth bags or jute sacks and weighted with stones to express the water. This de-watering process can take up to a week, or sometimes longer. During this time, a characteristic sour flavour develops due to fermentation occurring in the cassava pulp. The stone-press technique is progressively being replaced by various types of mechanical presses (screw-press, jack-press, and etc..) which shorten the de-watering time. In the mechanised production of *farinha* in Brazil, powerful hydraulic presses are used to de-water cassava pulp in just a few minutes. When a mechanical press is used in West Africa, the cassava root mash is first left to ferment with no pressure applied on the cassava mash. When the fermentation is estimated complete in the *gari* process, the pulp is removed from the bag, pressed, sieved to remove coarse materials, and roasted on a metal pan to make light and crispy granules. The *gari* so obtained is a granular free-flowing meal, white in colour, or yellow if palm oil has been used.

Gari is consumed in a variety of ways (Doku, 1969). Upon adding cold water, the granules swell and soften but retain their individuality; as such, they can be added in a soup or stew. It goes well with cowpea stew. Very hot water can be used to coalesce the individual *gari* granules and form a thick paste. In this form it is called *eba* in Nigeria and can be used just like the cold preparation. Many more variations exist in the utilisation of *gari* as food in West Africa, all mixing the cassava product with other food items to make a complete meal.

Fufu

In Ghana, *fufu* (or *foofoo*) refers to sticky dough prepared from any boiled then pounded starchy food including yam, cocoyam and plantain, as well as cassava. To make *fufu*, cassava roots are first boiled and then pounded in a mortar until a homogenous dough is obtained, which may take about 15 minutes. It is eaten immediately along with a stew made from a variety of meat and vegetables. If left standing, the *fufu* will harden and become unfit for eating.

In Nigeria, *fufu* is the name of a food made from cassava roots soaked for 3 to 5 days, mashed and directly cooked into a dough. However, in Central Africa, *fufu* refers to dough obtained by mixing any type of flour in hot water. One can therefore make cassava *fufu*, corn *fufu*, or sorghum *fufu.* When used alone, however, the term *fufu* refers to the dough made from cassava flour. This flour can be obtained in two ways: sun-drying of fresh cassava whole roots or chips and milling them into flour when dry; or first soaking whole roots in water for 3 to 5 days. Soaking is usually the preferred process if water is in abundance; where water is scarce, cassava flour is made from sun-dried roots. Cassava flour from sun-dried roots is common in East Africa where it is used to make a product similar to the Central African *fufu* but called *ugali*.

Kwanga

Kwanga (or *chickwangue*) is a popular fermented cassava product in Central Africa, particularly in the Congo and in Cameroon where it is called *miondo* and *bobolo*. To make it cassava roots fermented by three days of soaking in water are mashed and steamed. The steamed mash is kneaded into smooth dough which is wrapped in leaves and steamed. After steaming, the wrapped cassava is allowed to cool. The product can be consumed warm or cold. Its shelf life is about 3 to 7 days at room temperature if the wrapping is not open. Otherwise it will dry up and become unfit for eating or it will support microbial growth.

Cassava leaves

In many tropical countries, cassava leaves constitute a highly prized vegetable. Young tender leaves are usually selected, pounded and boiled for 15 to 30 minutes; various ingredients are then added to taste. In Africa, the highest consumption rates are found in central Africa and in East Africa; however, cassava leaves are widely consumed in several countries of West Africa such as Sierra Leone, Guinea and Liberia. Even though the concentration of cyanogenic glucosides in cassava leaves is 5 to 10 times greater than that of the root parenchyma, there are no reports of toxicity associated with the consumption of cassava leaves. When leaves are processed, their cyanogenic potential is considerably reduced during pounding, and after boiling it is virtually reduced to nil (Bokanga, 1995). A similar phenomenon is observed when cassava roots are ground into a mash, de-watered and heated on a flat hot surface to produce *farinha* in Brazil and *gari* in West Africa. Whereas cassava roots are well recognised as deficient in protein (average 1 percent on fresh weight basis), the leaves contain 7 to 10 percent protein (equivalent to about 30 percent protein on a dry weight basis). The protein content of cassava leaves was determined in 181 varieties and was found to range from 26 to 42 percent (IITA, 1974). Much of this protein is made up of the enzyme linamarase; its activity was found to be about 200 times greater in the leaves than it was in the roots (Bokanga, 1995).

Cassava leaves have a good potential as a source of protein in animal feed. They have the same protein content and the same value as feed as alfalfa, a well-established animal feed in temperate climates. Dried alfalfa foliage is exported to Asia, particularly to Japan, for use as animal feed. In Brazil and in some Asian countries, whole cassava plants (foliage, stems and roots) are shredded and ensiled to make feed for cattle and pigs.

1.4 Secondary and derived product

Fermentation

A recent survey of the modes of utilisation of cassava in Africa has revealed that nearly three out of four cassava-based foods encountered in the survey were fermented products (Westby, 1991). Three types of fermentation are generally distinguished: a submerged fermentation, in which cassava roots, whole or in large pieces, are steeped in water for a period of 3 to 5 days; a mash fermentation, in which a mash is obtained by grating or rasping fresh cassava roots, and the mash is left to ferment in a container for several days; and a low-moisture fermentation whereby peeled cassava roots are heaped together and fungal growth is allowed to develop at the surface of the roots.

Nearly all fermentation relies on the fortuitous presence of microbes on the roots and/or in the water, and on the prevailing favourable conditions for the production of the desired product. In some instances, a small amount of a previous batch is kept and used to inoculate the next, but the fermentation is allowed to follow its natural course with little or no attempt to control it. As a result, the flavour, aroma and texture of the fermented product vary with the season, location, and producer.

The micro-organisms associated with cassava fermentation are mostly lactic acid bacteria (*Lactobacillus plantarum*, *Streptococcus faecium* and *Leuconostoc mesenteroides*) and spore-forming bacteria such as *Bacillus sp.* (Bokanga, 1989; Nwankwo, et al., 1989; Okafor et al., 1984; Ngaba and Lee, 1979; Abe and Lindsay, 1978). Lactic acid bacteria are mainly responsible for the rapid acidification that characterises cassava fermentation. The *Bacillus sp.* seem to be responsible for inducing the retting of cassava root tissues during the submerged fermentation of whole roots. Other micro-organisms, such as *Corynebacterium sp.*, enterobacteriaceae, yeast and moulds have been reported (Akinrele, 1964; Collard and Levi, 1959), but they are usually present in low numbers and their role is not clearly understood.

It is interesting to note that the micro-organisms found in cassava fermentations are similar to those found in milk fermentation. Some of them may possess unique properties that may be of nutritional or industrial importance, e.g. over-secretion of a specific nutrient or chemical, production of bacteriocins, etc. It is therefore essential that the study of indigenous cassava fermentation should receive more attention than it has in the past.

1.5 Requirements for export

The amount of cassava exported out of Africa and the Americas is negligible, while it is estimated that 27 percent of the Asian cassava production is exported (See Table 8). Thailand accounts for 90 percent of Asian cassava exports and Indonesia about 9 percent. The largest importer of cassava is the European Union which defines four types of cassava products:

i. cassava pellets made by compressing flour or starch;

ii. fresh cassava for human consumption: this category consist of whole and fresh cassava, or peeled and frozen, or sliced in small pieces, packaged in readily marketable form in packages containing less than 28 kg of product;

iii. dried cassava chips

iv. starch

The near-totality of traded cassava (99.6 percent) is in the form of cassava chips (See Table 9). Eight countries (Netherlands, Spain, Belgium, Luxembourg, Portugal, Germany, France and Italy) absorb almost all the cassava entering Europe. In the period 1994-1996, the Netherlands alone accounted for 46 percent of the European cassava imports.

The Thai government has defined the standards of cassava chips for export. Two grades can be distinguished:

A *special grade* refers to dried (but not milled) cassava roots, light in colour, without foreign matter and free from unusual odour; it should have a starch and free sugars content of not less than 72 percent by weight and a moisture content of not more than 13 percent by weight. If sand or fibre is present, they should not exceed 2 percent and 4 percent by weight respectively.

A *first grade* is defined like the special grade except that the maximum permissible level for moisture content is 14 percent by weight.

Table 8. Average annual export of cassava products to the European Union in the period 1994-1996 (in metric tons)

Producing Region	Fresh	Pellets	Chips	Starch	Total
Africa	159	25	21,031	12	21,227
Americas	3,935	5	33,223	821	37,984
Asia	20,925	1,238	3,766,885	8,447	3,797,696
Total	25,019	1,468	3,821,139	9,281	3,856,907

Source: European Commission for Agriculture, 1997

Table 9. Average annual imports of cassava products into the European Community in the period 1994-1996 (in metric tons)

Importing country	Fresh	Pellets	Chips	Starch	Total
Netherlands	1	2,784	1,754,629	1,430	1,758,844
Spain	1,433	0	864,540	7	865,980
Belgium/Luxembourg	7	48	379,629	86	379,770
Portugal	0	1	328,539	23	328,563
Germany	4	3	203,394	1,806	205,207
France	4	293	199,030	3,867	203,194
Italy	2	1	75,745	15	75,763
Ireland	0	0	6,567	0	6,567
United Kingdom	17	1,033	92	1,761	2,903
Denmark	0	0	2,827	10	2,837
Sweden	0	2	0	274	276
Total	1,468	4,165	3,814,992	9,279	3,829,904

Source: European Commission for Agriculture, 1997.

2. Post-Production Operations

2.1 Post-harvest biodeterioration

Cassava roots, when left attached to the main stem, can remain in the ground for several months without becoming inedible; farmers do often leave cassava plants in the field as a security against drought, famine or other unforeseen food shortage. It is from this property that cassava has earned its name as a 'famine reserve crop'. However, once the roots have been harvested, they start deteriorating within 2 to 3 days, and rapidly become of little value for consumption or industrial applications.

Two types of deterioration are known to occur. The first to appear -- therefrom named 'primary deterioration' -- consists of physiological changes characterised by an internal root discoloration called vascular streaking or vascular discoloration (Averre, 1967). It is displayed as blue-black or brownish occlusions and chemical deposits. The time to onset of primary deterioration and the rate at which it progresses, the intensity, pattern and distribution of the discoloration varies between cultivars and roots of the same plant. Some varieties deteriorate so fast they become inedible 24 hours after harvest (Booth, 1976) while others have been reported to stand for 7 to 11 days at room temperature without any sign of discoloration (Montaldo, 1973). From a biochemical point of view, primary deterioration of

cassava roots is associated with a conversion of some of the starch to sugars (Booth *et al* 1976), an accumulation of cyanogenic glucosides, a decrease in linamarase activity (Kojima *et al.* 1983), and the onset of a number of enzymatic reactions leading to the accumulation of coloured compounds (Wheatley and Schwabe, 1985).
There is a strong association between the onset of primary deterioration and the occurrence of various forms of mechanical damage. Due to the nature of harvesting and handling operations, mechanical damage is unavoidable; cutting the root off the plant creates a wound; digging utensils may cut or scrap the roots. Breaking off of the root tips and bruising do occur during transportation and handling. Wounds and bruises are the triggers of primary deterioration. Booth (1976) found that primary deterioration was essentially a wound response being initiated near the region of mechanical damage; unlike in other storage organs (e.g. sweet potato), the response is not localised at the surface, but spreads down the root. Wounds and bruises also constitute points of entry for micro-organisms leading to the second stage of cassava root spoilage, known as "secondary deterioration".
Secondary deterioration is induced by micro-organisms that cause rotting. Two types of rot have been identified. Under aerobic conditions, fungi cause a dry rot which results in discoloration and a slight rise in acidity; under anaerobic conditions, bacterial activity (mainly due to *Bacillus* sp.) predominates, giving rise to rapid development of acidity (Ingram and Humphries, 1972). Most of these organisms behave as wound pathogens and infect roots through the sites of injury, and this usually occurs after primary deterioration has set in, and the roots have already lost their appeal to consumers.

2.2 Harvesting

Cassava roots can be harvested at any time of the year. Some farmers harvest as early as six months after planting while others may leave the crop for 18 to 24 months. The food quality of roots, particularly the starch content, increases with time up to an optimal period of 12 to 15 months after planting, after which there is a loss of quality, mainly due to increased lignification. During the dry season, cassava usually drops its leaves. At the onset of rains, a dramatic shift in root quality takes place, probably due to a remobilization of starch towards new leaf formation: the mealy texture of boiled cassava root is often lost, and roots can no longer be used for this purpose.
Harvesting cassava roots is usually done by hand; it is easy if the soil are sandy or during the rainy season. In heavier soils or during the dry season, harvesting usually requires digging around the roots to free them and lifting the plant. To facilitate lifting, the plant is usually cut down about 30 to 50 cm above ground. The protruding stem is used to lift the roots out of the ground. While lifting, care should be taken not to break the roots, as this will lead to losses if broken roots are not retrieved from the soil and to contamination that may evolve into spoilage.
After clearing the land, harvesting is the most labour-intensive operation, and agricultural engineers have sought to mechanise it. Mechanical harvesting of cassava is difficult because of the non-uniform geometry of the roots in the ground. Nevertheless a few cassava harvesters have been designed and some are in operation, mostly by large-scale farmers. The cost of mechanical harvesting is too high for resource-pour farmers.
Young leaves and shoots of cassava are also harvested to be consumed as vegetables and may be as important as roots for generating cash income. Excessive harvesting of the leaves can have a negative effect on the yield of roots. However, it has been shown in D.R. Congo where cassava leaves are extensively commercialised, an optimal leaf harvesting schedule of once every one or two months will result in higher overall returns for the farmer (Lutaladio and Ezumah, 1981).

2.2.1 Methods

The Amerindians, who first cultivated cassava, also devised numerous processing techniques not only to increase the palatability of cassava and to extend its shelf life, but also to decrease its cyanogenic potential. Today, a great diversity of processing methods are found in the various parts of the world where cassava is consumed (Lancaster *et al.*,1982). They consist of combinations of the primary processing steps described below.

Peeling

The first step in processing cassava roots is often to remove the peel; this result in a great reduction the cyanogenic potential of the raw material, because the peel represents about 15 percent of the weight of the root, and its cyanogen content is usually 5 to 10 times greater than that of the root parenchyma. However, the peel also contains large amounts of the enzyme linamarase which is important in the detoxification of cassava during processing. For instance, grinding cassava roots without removing the peel, as is done in the manufacture of the Brazilian farinha, ensures an almost total elimination of cyanogens from cassava. Peeling is usually done by hand using a knife; the process is slow and labour-intensive, averaging 25 kg per man-hour, but it gives the best results. The Post-harvest Engineering Unit of IITA has developed a cassava peeling tool that is simple, can be fabricated locally and gives minimum peeling losses (See Figure 4a). Mechanical peelers are generally wasteful and with low efficiency. All solutions, including chemical ones that have been developed so far have proved rather impractical. For several years more, peeling cassava will remain as a source of employment and income for rural dwellers, particularly if cassava-based agro-industries develop around cassava farms.

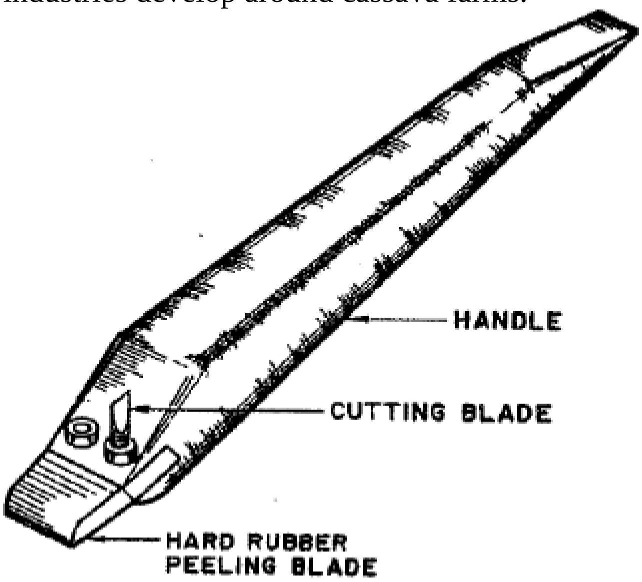


Figure 4a: Cassava peeling tool

Boiling

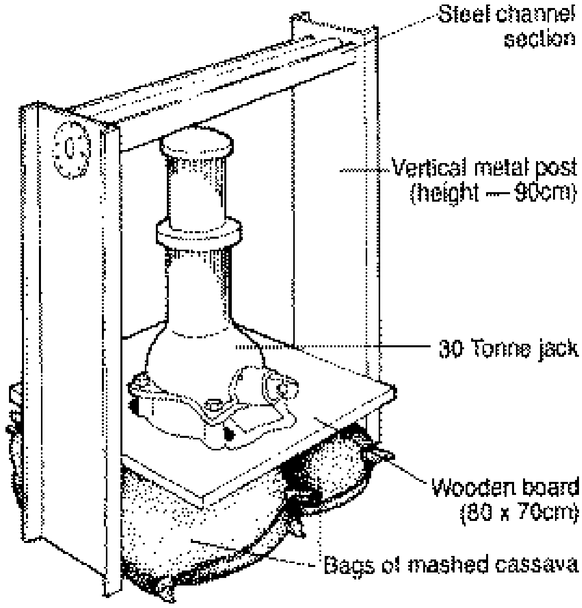
Cassava is often consumed as a vegetable after boiling for 15 to 45 minutes. Some cassava varieties give a soft, mealy and easy to mash boiled roots. In some parts of Africa, after boiling, the roots from these types of varieties are pounded into a smooth paste called *fufu*. Other varieties give roots which when boiled remain hard and are waxy; these cannot be pounded into *fufu*. IITA and several African countries have breeding programs to develop the mealy-type cassava varieties. Wherever boiled cassava is consumed, mealiness is the main quality characteristic.

Size reduction: chipping and grating

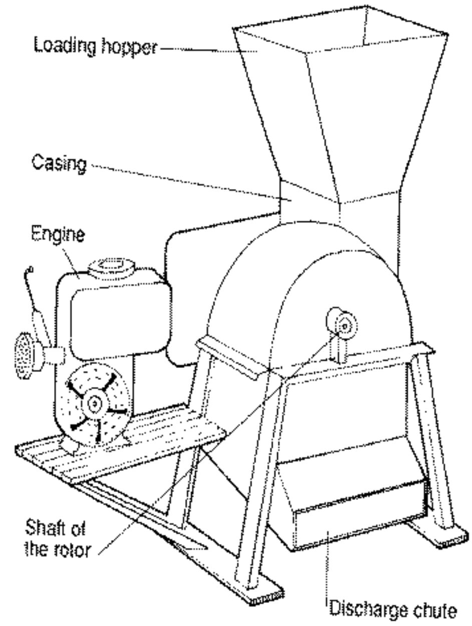
The size of cassava roots is usually too large to process and is usually reduced prior to further processing. At the home level, cassava roots are chipped manually using a knife. This process is slow and produces large and irregular chips that take 3 to 7 days to dry and impart a sour and musty taste, actually preferred by some consumers, to the food made from the dry chips. Mechanical chippers have the advantage of producing smaller and uniform chips that dry rapidly. The drying rate depends on the geometry of the chips and the amount of chips per unit of drying surface. Flat chips tend to stick to each other and reduce the flow of removal of moisture between chips that are stuck together. IITA has designed a low-cost chipper that produces 'finger' chips of about 5mm thickness and a length depending on the size of the cassava roots (IITA, 1996). These chips can dry after 6 to 8 hours of exposure to the sun. When manually operated, the chipper has a capacity of 60-70 kg/hr; but an electric, gasoline or diesel engine can power it with a capacity of 1000kg/hr.

The initial step of several processes for the preparation of foods from cassava is pulping, either by grating or by crushing freshly harvested cassava roots. Examples of foods prepared in this fashion are *gari* in Nigeria, *farinha de mandioca* in Brazil, *cassava bread* in various countries of Latin America and the Caribbean islands (Lancaster *et al.,* 1982). Cassava starch extraction is also carried on after pulping. The pulping process results in the disintegration of cassava tissues, which favours the contact between linamarase and the cyanogenic glucosides. Processes that begin with pulping usually result in the greatest detoxification of the final product. This is the case of the farinha and gari processes, and of the starch extraction process. Once the pulp is obtained, it is usually squeezed to remove the juice. The remaining cake is further processed into food. The juice is discarded, or in some instances, it is used to prepare sauces or beverages (Lancaster *et al.,* 1982). To make starch, the pulp is extensively washed with water to separate the starch granules from the soluble component of the pulp.

Pulping is the first step in the preparation of gari and *attiéké* (West Africa), farinha (Brazil, Caribbean). In Nigeria, the process of grating cassava has been widely mechanised; there are many types of grating machines to choose from. IITA has also developed a grating machine which can be manually operated or equipped with an engine (See Figure 5). The manual grater has a capacity of about 30 kg/hr, while the motorised grater has a capacity of 800 kg/hr. Young roots are usually easier to process, while roots from plants that are more than 18 months old require a longer time to grate because they are generally more fibrous and oppose a greater resistance to the grating process (IITA, 1996).



Hydraulic jack press



A typical cassava grater

Figure 5. Equipment used in simple cassava processing

Pressing

After grating cassava, the next processing step is generally pressing the grated pulp to reduce its moisture content. The Amerindians who have been processing cassava for two millennia developed an ingenious press shaped like a long thin basket-weave tube called *´tipiti'*. The tipiti would be filled with cassava mash, hung on a branch of a tree and stretched from the bottom; its volume would reduce and water would be squeezed out of the mash. In Africa, people used heavy stone placed on top of bags or baskets filled with cassava mash. More recently, screw presses and jack presses (See Figure 5) are used for greater efficiency and speed. In Brazil where grating and pressing cassava have been industrialised, hydraulic presses providing pressures of up to 25 kg/cm^2 are quite common. The moisture content of the mash is reduced from 60-70 percent to about 50 percent. The pressing time can be as short as 15 minutes with the hydraulic press or as long as 4 days or more when stones are relied upon.
The cake obtained after pressing needs to be broken down into granules. This can be done manually or mechanically by passing it again in a grating machine. The powdery granules obtained can then be further processed into the desired products.

2.2.2 Special requirements

Cyanogenesis and safety issues

The single most important constraint in the expansion of cassava utilisation is its association with cyanide. It is essential that this association be well understood for the promotion of the crop.
Cyanogenesis, the ability of plants to produce, under some circumstances, the toxic hydrogen cyanide (HCN), exists in over 2000 plant species belonging to more than 100 families. In all species so far examined, HCN is never produced and stored at any stage of plant growth. The

plants produce complex compounds, mainly glucosides, but in some case lipids, which may break down to produce HCN. Those compounds are therefore known as cyanogenic compounds. Plants also produce enzymes that break down the cyanogenic compounds but they are both always stored separately inside plant cells. It is only when the plant is damaged, and the structural integrity of the plant cells is destroyed that the enzyme acts on the cyanogenic compounds to produce cyanide.

Cassava produces two cyanogenic glucosides, linamarin and lotaustralin, in about 10 to 1 ratio. The amino acids valine and isoleucine are the precursors used in the synthesis of linamarin and lotaustralin respectively. The metabolic pathway for converting valine to linamarin has been elucidated by Koch *et al.* (1992).

In cassava plant cells, the cyanogenic glucosides are stored inside the vacuoles in the cytoplasm while the enzyme capable of degrading them is located in the cell wall outside the cytoplasm (Mpkong et al, 1991). Therefore, in intact cells the breakdown of cyanogenic glucosides would not occur. When cassava tissues are bruised and the cellular structures are disrupted, linamarin and lotaustralin come in contact with linamarase and are degraded.

The breakdown of linamarin leads to the formation of acetone cyanohydrin and glucose (Figure 3). At pH above 5, the acetone cyanohydrin will spontaneously break down into acetone and HCN. This breakdown may also be catalysed by the enzyme hydroxynitrile lyase (HNL) which is also present in cassava. Once HCN is produced, it will dissipate in the air (since its boiling temperature is 25.7^{o}C). In damaged plant tissues, which includes processed roots and leaves, it is possible to find non-hydrolysed cyanogenic glucosides, cyanohydrins and traces of HCN. The term cyanogen refers to any of these three compounds.

Old analytical methods for quantifying cyanogens found in the literature often have the shortcoming that they do not achieve complete hydrolysis of cyanogenic glucosides, and therefore, under-estimate. A breakthrough was achieved with the method developed by Cooke (1978). In this method, all the cyanogens are extracted from the sample under conditions that stabilise them, and are quantitatively converted to cyanide ions that are specifically measured by a modified Epstein reaction. The entity measured in this fashion is termed "total cyanogen content". Modifications of the Cooke's method (O'Brien *et al.*, 1990; Essers *et al.*, 1993) have now made it possible to distinctively quantify hydrocyanic acid, cyanohydrins and cyanogenic glucosides.

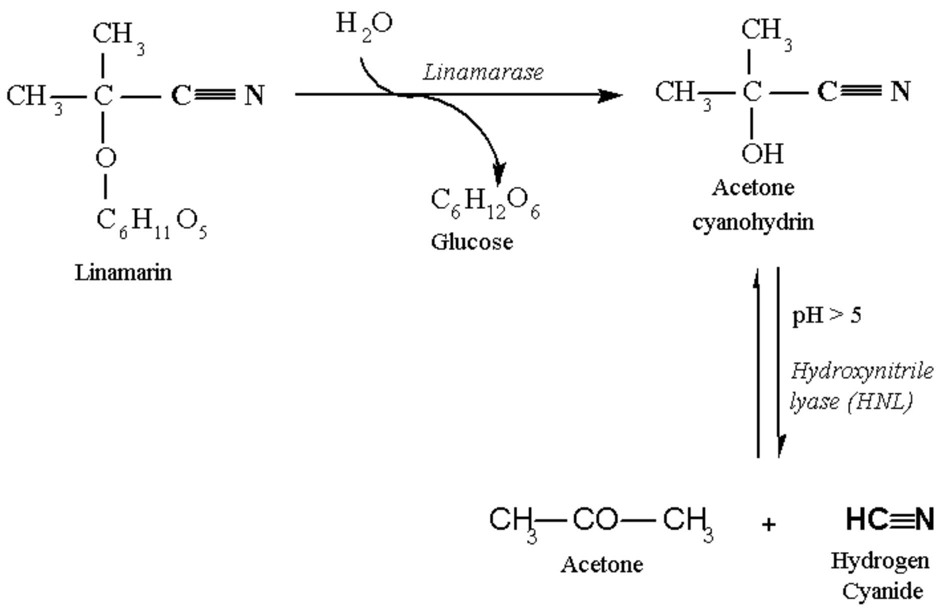


Figure 3. Enzymatic hydrolysis of linamarin

The term "free cyanide" is used by some authors to refer to hydrocyanic acid and by others to the sum of hydrocyanic acid and cyanohydrins. Some authors use the term "bound cyanide" to refer to cyanogenic glucosides, while others may use it to refer to hydrocyanic acid bound to albumin and other blood proteins as part of *in vivo* cyanide detoxification processes. In the case of total cyanogen content defined above, what this value represent is the maximum amount of HCN that could be obtained from a sample. It therefore represents the CYANOGENIC POTENTIAL (sometimes abbreviated as CNP) of the sample and is usually expressed as mg HCN-equivalent per 100 g, or per kg of sample, taking care to specify whether the value is expressed on fresh or dry weight basis. Because of its simplicity, safety and low cost of reagents used, the method proposed by Essers *et al*. (1993) is recommended. Cooke (1978) has studied the stability of the cyanohydrin. He found that at 30C and pH 6 it had a half-life of about 30 minutes, and that alkaline pH favoured its dissociation, while acid pH favoured its stability. This is important for the quantification of cyanogens and for the interpretation of cyanogen content of cassava reported in the literature.

Cyanogenic glucosides are not uniformly distributed in the various tissues of cassava plants. The largest concentration is usually found in the peel's cortex, and the lowest in the central pith; the leaves often contain the next highest concentration (De Bruijn, 1971). Younger tissues contain more total cyanide than older ones. In the root, the section closest to the stem (proximal) contains more total cyanide than the middle and distal sections; there is a shallow longitudinal gradient from the proximal to the distal end. From the peel side of the central pith to the centre of the root, the cyanogenic glucosides gradient is more pronounced; the concentration of cyanogenic glucosides is greatest in the outermost 2-3 mm layer and drops sharply towards the centre (Kojima *et al.,* 1983).

Among 67 varieties analysed by de Bruijn (1971), the cyanogenic potential varied from 31 to 630 mg/kg in the root (fresh weight) and from 540 to 1450 mg/kg in the leaves (fresh weight). Similar ranges of cyanogenic potential were found in larger collections of varieties at the International Institute of Tropical Agriculture (IITA) in Nigeria (851 genotypes) and at the Centro Internacional de Agricultura Tropical (CIAT) in Colombia (560 genotypes) (Bokanga, 1994). No correlation was found between the total cyanogenic potentials of roots and leaves. Recent and old investigations have also confirmed this lack of correlation (Bokanga, 1994; Cooke *et al.*, 1978a).

Cassava plants are arbitrarily classified into low- and high-cyanide varieties depending on the cyanogen content of their roots: low-cyanide varieties having roots with less than 100mg HCN-equivalent per kg (fresh weight), and the roots of high-cyanide varieties being above that figure (Hahn and Keyser, 1985). This is not unrelated to the toxicity classification proposed by Bolhuis (1954) in which cassava roots containing up to 50 mg HCN-equivalent per kg are considered innocuous, 50 to 100 mg HCN-equivalent per kg are considered moderately poisonous, and above 100 mg HCN-equivalent are considered dangerously poisonous. The scientific bases for these classifications have never been explained and required more investigation.

The organoleptic descriptors 'sweet' and 'bitter' are often used to characterise cassava varieties. Although earlier reports have associated bitter/sweet varieties with high/low levels of cyanogenic glucosides (Bolhuis, 1954), a cause-effect relationship has not been established (Coursey, 1973; Pereira *et al.*, 1981). A bitter compound other than the cyanogenic glucosides has been isolated (King and Bradbury, 1996). Nevertheless, recent surveys in Africa have shown that farmers associate bitterness of cassava roots with toxicity (Chiwona-Karltun, in press).

Cassava consumption and health

Reported toxic effects of cassava are relatively rare in comparison with its wide use as a staple. A comprehensive review on this topic has been published (Bokanga et al., 1994). High

and continuous consumption of cassava has been associated with various diseases and nutritional disorders: tropical ataxic neuropathy (Osuntokun, 1972), goitre and cretinism (Ermans *et al.*, 1983), spastic paraparesis (Mozambique Ministry of Health, 1984; Cliff *et al.*, 1985) or konzo (Howlett et al., 1990). Contrary to the terminology used in earlier publications, there is no cyanide (HCN) of importance in cassava products. These contain variable amounts of cyanogenic glucosides and cyanohydrins. Upon consumption, cyanohydrins can readily decompose into cyanide, but cyanogenic glucosides are partly excreted unchanged in the urine. The cyanide produced is rapidly converted to thiocyanate by the enzyme rhodanese, which is widely distributed in the human body, with the highest concentration being in the liver and kidneys (Auriga and Koj, 1975). Thiocyanate has a known goitrogenic effect: it interferes with the ability of the body to use a limited supply of dietary iodine. However, a high thiocyanate load does not show a goitrogenic effect if the dietary iodine intake is adequate (Delange et al., 1994). Therefore, nutritionists should be aware of the potential goitrogenic effect of cassava in populations in tropical countries with marginal iodine supply and with cassava processing methods that are not efficient in reducing the cyanogen content of cassava food products.
There is increasing evidence to link prolonged consumption of insufficiently processed cassava with a newly described disease named *konzo* (Howlett, 1994; Tylleskar, 1994). Konzo is a paralytic disease (previously known as endemic spastic paraparesis) of abrupt onset appearing in very poor rural communities whose diets almost exclusively consist of bitter cassava roots. According to Tylleskar (1994), there are three prerequisites for the occurrence of konzo; a farming system dominated by bitter cassava, insufficient cassava processing that leaves high residual levels of cyanogens in cassava foods, and a protein deficient diet. Populations growing bitter cassava usually know how to process cassava into safe products (Dufour, 1994), and meeting one's protein requirements is a major priority in all communities. This explains why the occurrence of konzo is so rare and tends to be associated with agroecological disasters such as severe droughts (Howlett et al., 1990), with civil strife (Cliff, 1994) and with economic disturbances (Banea et al., 1992). It should also be emphasised that for millions of consumers, well-processed cassava is a staple food with no associated negative effects.

2.3 Transportation

The first post-harvest task is transportation from the site of production and harvest to the site of processing and utilisation. Tshiunza et al. (1997) estimated that, on average, 70 person-days are needed to carry the harvest from one hectare of land (about 12 tons) over a distance of 1.5 km. The study which covered the six major African cassava producing countries (Cote d'Ivoire, D.R. Congo, Ghana, Nigeria and Tanzania) revealed that 85 percent of the farm output is carried directly to farmers' homes, 10 percent directly to market places and 5 percent to processing places. Transportation from field to home is by way of motor vehicle (15 percent), bicycles (9 percent), carts (6 percent), but mostly by head-load or back-load (70 percent). Women represent 81 percent of people involved in cassava transportation; they carry cassava to all destinations, while men's transportation is almost exclusively directed to the home (Nweke et al., in press). Harvesting and transportation are the most labour-intensive activities in cassava production; together they account for about 50 percent of labour needs for cassava production.

2.4 Drying

Reducing their moisture to a point where all physiological reactions and microbial growth are inhibited can tremendously increase the short shelf-life of cassava roots. In cassava, this point is at 14 percent moisture content, corresponding to a water activity of 0.70. The removal of moisture from cassava roots can be accomplished either by drying in the sun or in an oven. The most common method of drying cassava is sun-drying; moisture content is usually brought down to 8-12 percent. Cassava chips or granules from a grater are spread on a drying surface exposed to sunrays. The more chips on a drying surface, the slower the drying rate will be. Thin chips dry faster than thicker ones. It should be noted that the quality of the chips (e.g. starch content, white colour) is higher if the drying time is short. However, the cyanogenic potential of cassava decreases when the drying time is longer. Therefore, drying parameters that affect the drying rate, especially the loading rate (weight of drying material per unit area of drying surface), are important in determining the residual cyanogen content of the dried cassava.

2.5 Storage systems for cassava

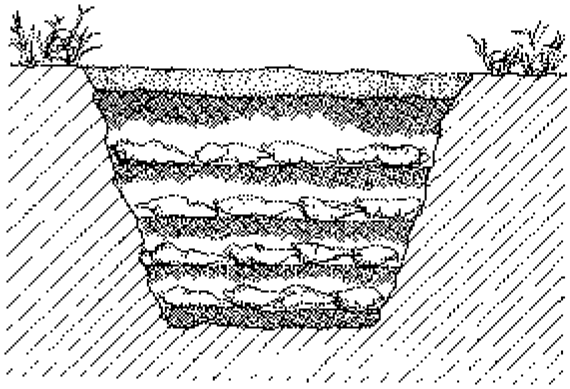
The high perishability of cassava roots has prompted cassava consuming populations to develop storage schemes that alleviate the problem. There are reports that, 300 years ago, Amazonian Indians successfully stored fresh cassava roots by burying them in the soil, and that, in Mauritius 250 years ago, fresh cassava roots were stored in straw-lined trenches for periods of up to 12 months (Booth and Coursey, 1974). Inspired by these reports, researchers CIAT developed a clamp storage system similar in design to the European potato clamp (Cock, 1985; Richard and Coursey, 1981).

In this system, a conical pile of 300-500 kg of fresh cassava roots is seated on a circular bed of straw and covered with more straw. The whole unit is covered with soil to a thickness of 10 - 15 cm, the soil being dug from around the clamp so as to form a drainage ditch. With this storage system, acceptable levels of loss (0 - 20 percent) were achieved for periods of up to 2 months.

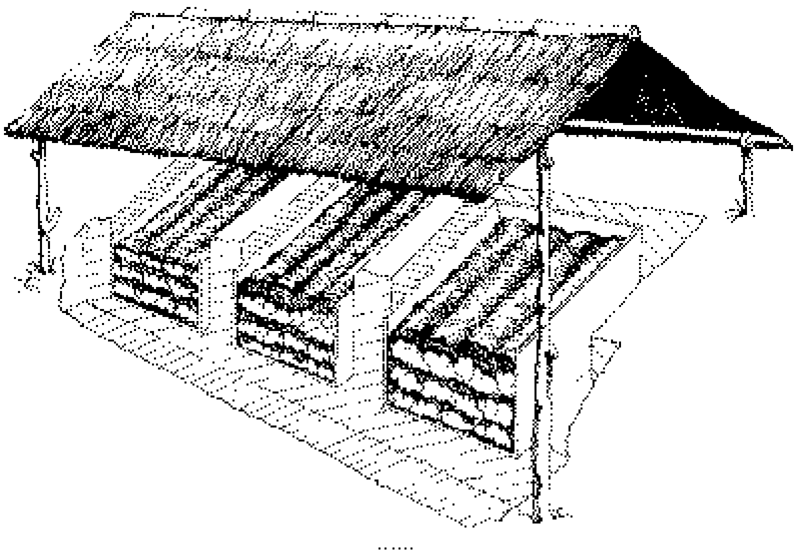
It was noticed during this storage time that bruised or otherwise injured roots tend to undergo a wound-healing response that prevent vascular discoloration or reversed it. This "curing" was correlated with a resistance to discoloration by application of exogenous scopoletin (Wheatley and Schwabe, 1985).

However, clamp storage performs less well during the hot season. The temperature inside the clamp easily reaches 40^{o}C, and heavy losses result even after 1 month of storage (Booth and Coursey, 1974). It has been reported by Marriott *et al.* (1979) that pruning of cassava plants by removing the top of the plant and leaving a short (20 cm) leafless stem 2 to 3 weeks before harvest resulted in roots resistant to primary deterioration even if the roots are severely damaged. These authors have put forth that this resistance was suggestive of a control mechanism for vascular streaking dependent on a factor (or factors) produced in the leaves and translocated to the roots. In accordance with this hypothesis are the findings of Wheatley and Schwabe (1985) that pruning reduces scopoletin accumulation in the roots but not the response to exogenous scopoletin.

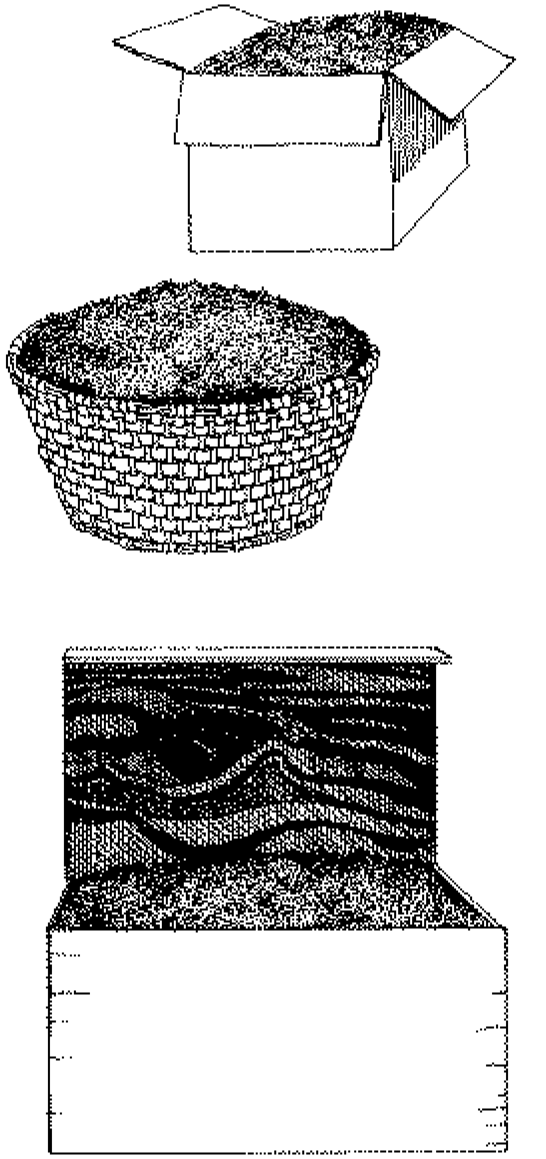
The clamp storage system is not compatible with transportation. To circumvent this, storage in boxes was designed (See Figure 4). Cassava roots are packed in boxes containing adsorbent material such as sawdust (Rickard and Coursey, 1981). The relative humidity inside the box is critical for a successful storage: too high, deterioration due to bacteria and fungi rapidly sets in; too low, vascular deterioration is not prevented.



Cassava tubers stored in a trench, covered with soil



Fully filled trenches under a protective shed



Three types of containers used for storing cassava tubers in sawdust

Figure 4. Storage systems for fresh cassava roots.

Packing cassava roots in polyethylene bags was tried and shown to preserve the roots for about 2 months (Cock, 1985). However, complete loss of the stored roots occurred as a result of microbial deterioration. Treating the roots with fungicides retarded the onset of spoilage (Rickard and Coursey, 1981).

The deterioration of cassava can be greatly reduced by cold storage. When kept below 4^{o}C, cassava roots do not show internal discoloration. They still, however, remain susceptible to spoilage by fungi (Rickard and Coursey, 1981). The same authors report that cassava roots could be kept satisfactorily under deep-freeze conditions but that changes in texture occurred in stored samples. Deep freezing of cassava has received little attention from researchers, probably due to the rationale that high-cost storage methods were not suitable for a low-cost commodity such as cassava.

The storage of processed cassava products presents fewer problems than the storage of fresh roots, especially when these products have low moisture content. The major causes of losses are insect pests and fungi (Ingram and Humphries, 1972). A survey of cassava chips processing areas of Benin, Ghana and Nigeria has indicated that the most common fungi were *Rhizopus sp.* (47.5 percent of total samples) and *Aspergillus sp.* (29.6 percent) (IITA, 1996). Fungi proliferate when the moisture content of cassava chips exceeds 14 percent. A large majority of the samples in all three countries had moisture content below the critical moisture level.

The Environmentally Sound Cassava Plant Protection (ESCaPP) project of the IITA has determined that the main insect feeding on dry cassava chips in Benin Republic was *Dinoderus sp.* (Saizonou, 1996). Other insects of importance belong to the species *Carpophilus sp.*, *Araecerus fasciculatus* and *Rhizopertha dominica.* Recently, the large grain borer, *Prostephanus truncatus* , a storage pest of maize, has been found infesting cassava chips in storage particularly during the rainy season. Infestation by all insects is heavier in the rainy season than in the dry season, is more prevalent in the humid zone than in the savannas, and is found more in large chips than in smaller ones (Dossou, 1996). Maximum infestation was found after 6 to 8 months in storage, at which time chips would fall into dust when squeezed.

3. Overall losses and labour requirements

It has been established that the post-harvest system of cassava requires more labour than most other staple crops (IITA, 1996). One hectare of cassava containing 10 tons of roots (the average root yield in Africa) needs approximately 721 man-hours to harvest and process: of this labour, 212 man-hours are needed for harvesting, 156 for handling, and 353 for processing.

The Collaborative Study of Cassava in Africa (COSCA) has shown that in 67 percent of cases, cassava processing activities were carried out by women only compared to 6 percent of cases for men only. Women along with children participated in another 19 percent of cases, and in 6 percent of cases women worked alongside men. This represents 92 percent participation by women in cassava processing (Nweke, 1994). However, the number of men involved in cassava processing increases as the opportunities for commercialisation increase (Ugwu and Ay, 1992). Although men are seldom involved in cassava processing operations, they tend to perform more of the heavy-duty farm operations. It was observed that as mechanised processing equipment (such as graters and mills) is acquired, men's participation in cassava processing tends to increase, since they often control and operate these machines. It appears therefore that gender role in cassava processing tends to change as processing becomes more mechanised.

With such a large number of processing steps, the opportunities for food loss in the whole system also become numerous. Major losses occur during processing (23.2 percent), harvesting (13.6 percent) and handling (8.5 percent). Harvesting losses are higher during the dry season because it is more difficult to dig; roots break and remain in the soil. The size, shape, hardness, moisture content and the type of equipment used affect the processing efficiency. Recently, IITA has assembled a technology package for cassava processing in rural areas (IITA, 1996). The package, which is in the form of a village processing centre, contains a chipping and grating machines, a pressing device, a mill, a gari fryer and sifters. Such package has been tested and found to reduce food losses during cassava processing from 22.3 percent to 10.1 percent and the labour input from 295.2 man-hours to 87.6 man-hours per 10 tons of cassava roots (See Figure 6).

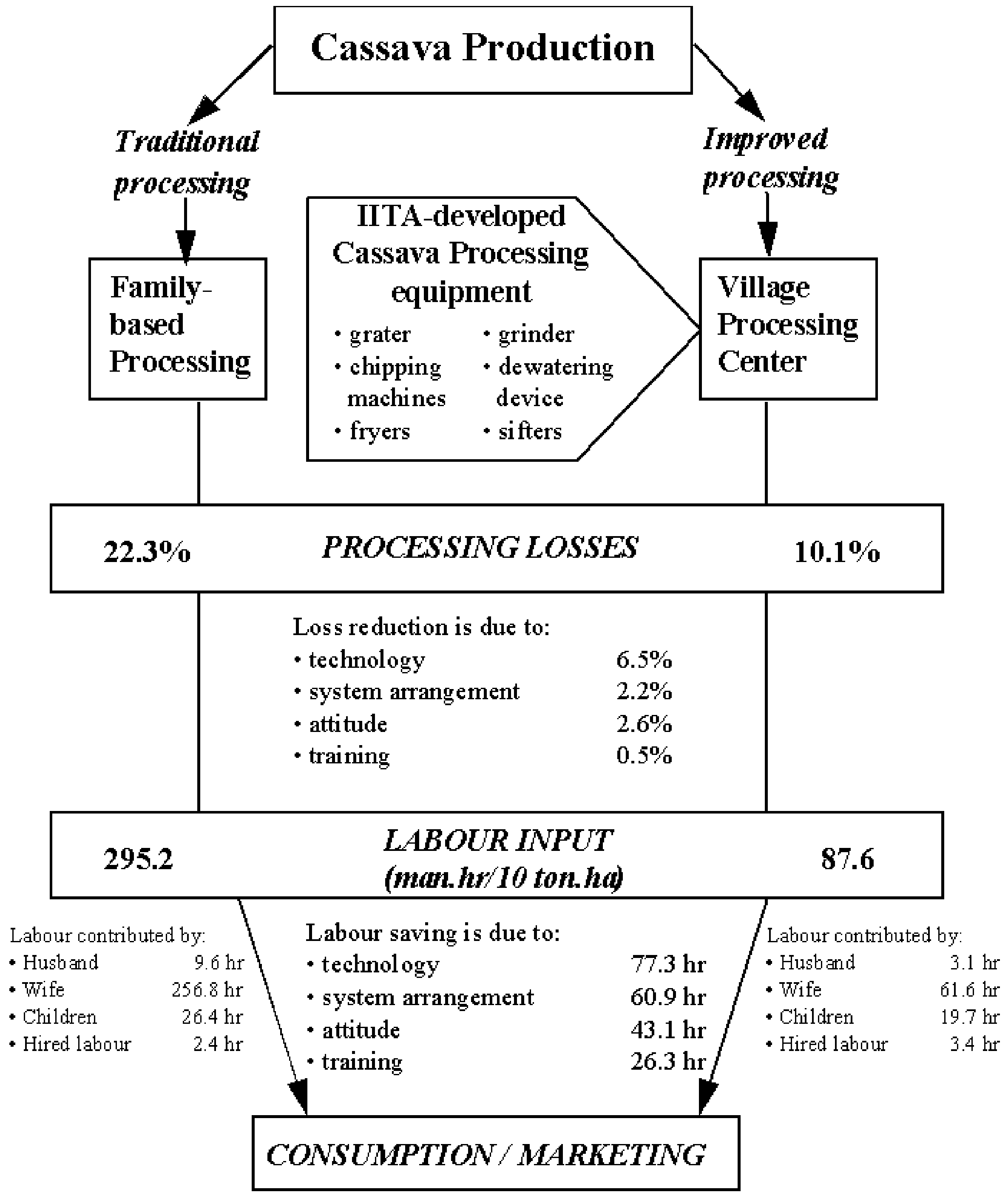


Figure 6. Effect of improved cassava processing on labour requirements and post-harvest food loss in the cassava post-harvest system. (Source: IITA, 1996).

A food exchange scheme based on the improved cassava processing technology package was tested in rural Nigeria (IITA, 1996). Using traditional methods, a family normally obtains 12 kg of gari or 18 kg of *lafun* per 100kg of fresh roots; using the new technology, the yield is 14 kg of gari or 20 kg of *lafun.* In the food exchange scheme, women bring their cassava roots to the processing centre and receive 12 percent of the roots weight as gari or 18 percent as lafun. They get what they would have obtained should they have processed the cassava by themselves. Moreover, the product they receive is also of better quality. The processing centre keeps the 2 percent of extra product and uses it to cover its processing and maintenance costs. Benefits to women are labour savings and improvement in food quality.

They have more time to devote to other chores, to leisure or to self-advancement. The processing centre is also an employment opportunity and source of income for women who are employed there. The food exchange scheme has shown that it can significantly improve the quality of life in a rural community.

4. Economic and social considerations

In the last 25 years, the world cassava production has been growing at over 2 percent per year. The crop has demonstrated its ability to provide food security to populations in the tropical world, particularly in Africa, that were faced with severe drought, civil unrest or economic breakdown. It has shown in Thailand that it can be a major foreign exchange earner and a building block for industrial development. In Latin America, particularly in Brazil, cassava has proven to be a reliable raw material for the food manufacturing industry and for animal feed production.

Recently, cassava production in Africa has been increasing at rates (4.2 percent) exceeding the population growth rate (see Table 6). In addition to playing its traditional role of providing food security and low cost food, cassava can be promoted as a modern food ingredient and as a modern input in the growing agro-industrial sector, thus raising farmers' income. The demand for animal feed (particularly poultry feed) is expected to increase in the next five years (FAO, 1997); production of starch and alcohol from cassava in Nigeria is only meeting 10 percent of the demand or less. Other African cassava producing countries are almost completely dependent on importation to meet their starch and alcohol needs.

To facilitate the adoption of cassava as viable raw material, the highly perishable cassava roots need to be transformed, as closer to the farm as possible, into stable products with a longer shelf life and lighter to transport than the fresh roots. Such product can be cassava chips or cassava flour. Its production technology is simple and inexpensive and can be adopted by farmers. In Nigeria, small-scale farmers have formed associations for processing cassava into flour that is sold to biscuit factories. Others are producing chips for the ethanol factory. In Ghana, there is a burgeoning cassava chips export market.

Due to policy changes in the European Community, cassava exports from Thailand to Europe have been declining, forcing Thailand to develop and expand its domestic utilisation of cassava. Food and non-food industries are steadily increasing their uptake of cassava (Titawatanakun, 1996). However, because of the large volume of cassava that is exported, domestic cassava prices in Thailand are determined by export prices. There is great pressure on Thai entrepreneurs to develop the most efficient cassava-based processes in order to remain in business.

In Africa, Asia and Latin America, the cassava post-harvest sector need to be relied upon to ensure that cassava continues to provide food, feed and industrial raw materials. Cassava research and development efforts should be expanded if cassava is to meet such expectation in the next millennium.

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6 Annex

6.1 List of tables

6.2 List of figures