Chapter 14

Cassava Utilization, Storage and Small-scale Processing

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Introduction

The importance of cassava in the world is mainly a reflection of the agronomic advantages of the crop. However, if the contribution that cassava can make to the livelihoods of poor people is to be increased, there is a need to consider also its postharvest handling, processing and marketing.

There are three major limitations to the increased utilization of cassava roots: poor shelf-life, low protein content and their naturally occurring cyanogens. Rapid postharvest deterioration means that processing is more important than for any of the other root crops. In addition to producing storable products, processing can also add value to the crop and provide employment opportunities.

Both cassava roots and leaves can be used as food, but economically the roots are usually more important, although in parts of some African countries, the leaves may be as important or more important than the roots. The tuberous roots can be 15–100 cm in length and reach a weight of 0.5–2.0 kg (Knoth, 1993). They have no function in vegetative propagation, which is done using stem cuttings. The roots contain large carbohydrate reserves, mainly as starch. Although the function of the starch-bearing tissue is not completely clear, it is assumed that it helps the plant to survive unfavourable conditions such as drought.

This chapter considers world cassava utilization and the nutritional value of the root and leaves for human consumption. The current state of knowledge on cassava storage and small-scale processing is presented with the emphasis on sub-Saharan Africa.

World Cassava Utilization

Total world cassava use is expected to increase from 172.7 million t to 275 million t in the period 1993–2020 using the International Food Policy Research Institute's (IFPRI's) baseline data. A higher prediction of demand and production growth puts the 2020 production at 291 million t (Scott *et al.*, 2000). In both projections cassava use in Africa is equivalent to 62% of total world production.

Cassava consumption

Cassava consumption has remained relatively constant in the period 1983–1996 (Table 14.1). Consumption per capita is highest in sub-Saharan Africa and increased between 1983 and 1996 which is remarkable given the region's high population growth rate of nearly 3% year^{-1} (Scott *et al.*, 2000).

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Cassava's main contribution to the human diet is as a source of carbohydrate. Table 14.2 shows the percentage contribution that cassava makes to the total energy consumption in the major consuming countries. Many of these nations are among the poorest in the world.

Cassava utilization

Cassava utilization patterns vary considerably in different parts of the world as indicated in Table 14.3. In Africa the majority of cassava produced (88%) is used for human food, with over 50% used in the form of processed products. Animal feed and use for starch are only minor uses of the crop. In the Americas animal feed is far more important, accounting for approximately one-third of consumption, and human food represents only 42% of production. Starch also represents an important use of cassava in South America. The situation in Asia is greatly influenced by the export of cassava chips by Thailand to the European Community for use as animal feed. If Thailand is disregarded, then it can be seen that consumption of fresh roots is the most important use of the crop (46% of production), starch is relatively important at over 10% of production and animal feed and export are minor uses.

Although the majority of data available for cassava relates to the roots, cassava leaves are important in some countries. In the Democratic Republic of Congo cassava leaves have greater market value than roots (Lutaladio and Ezumah, 1981). It has been estimated that cassava leaves account for approximately 68% of all vegetable output in the country (Tshibaka and Lumpungu, 1989).

Table 14.1. Per capita consumption (kilograms per capita) of cassava as food and feed, 1983 and 1996.

Region/country	1983	1996
Latin America	29	25
South-East Asia	2	1
India	7	6
Other South Asia	2	1
Sub-Saharan Africa	102	106
Developing countries	20	21
World	15	16

Data adapted from Scott *et al.* (2000).

Cassava's nutritional contribution to the diet

The composition of cassava roots is shown in Table 14.4. Cassava roots are a rich source of carbohydrate. Most of the carbohydrate is present as starch (31% of fresh weight; Table 14.4) with smaller amounts of free sugars (less than 1% of fresh weight). Cassava roots are low in protein (0.53%), although higher concentrations of 1.5% have been reported by Ekpenyong (1984), and fat (0.17%). Protein from other sources is therefore needed if cassava is to be part of a balanced diet.

Cassava is generally considered to have a high content of dietary fibre, magnesium, sodium, riboflavin, thiamin, nicotinic acid and citrate (Bradbury and Holloway, 1988). Iron and vitamin A are considered to be low. There are,

Table 14.2. Percentage contribution of cassava roots to the total energy intake in populations of the principal consuming nations in the period 1990–1992.

> 25%		15–25%		10–15%		5–10%	
DR Congo	54.0	Benin	21.8	Paraguay	14.3	Burundi	9.5
Mozambique	38.5	Tanzania	21.7	Comores	13.1	Zambia	9.3
Congo	35.2	Liberia	19.8	Cameroon	13.0	Chad	8.7
Angola	27.3	Togo	19.0	Ivory Coast	12.4	Rwanda	8.2
Ghana	26.0	Uganda	17.1	Gabon	11.1	Tonga	6.9
RCA	25.9	Madagascar	16.3	Guinea	10.8		
		Nigeria	15.4				

Source: Treche (1995).

Table 14.3. World utilization patterns of cassava. Figures are percentage of total production.

Area	Human food – fresh	Human food – processed	Animal feed	Starch	Export	Waste	Stock
World	30.8	33.8	11.5	5.5	7.0	10.0	1.4
Africa	37.9	50.8	1.4	< 1	< 1	9.5	< 1
Americas	18.5	23.9	33.4	9.6	< 1	14.0	< 1
Asia	33.6	21.7	2.9	8.6	23.0	6.3	3.9
Asia (without Thailand)	45.7	27.9	3.9	11.7	2.3	8.6	< 1

Source: Cock (1985).

Table 14.4. Composition of cassava roots in the Pacific Islands as reported by Bradbury and Holloway (1988).

Component	Roots	Leaves
Moisture (%)	62.8	74.8
Energy (kJ 100 g^{-1})	580	
Protein (%)	0.53	5.1
Fat (%)	0.17	2.0
Starch (%)	31.0	–
Sugar (%)	0.83	–
Dietary fibre (%)	1.48	5.1
Ash (%)	0.84	2.7
Minerals (mg 100 g^{-1})		
Calcium	20	350
Potassium	302	56
Phosphate	46	–
Magnesium	30	–
Iron	0.23	–

Values for leaves are from Gomez and Valdivieso (1985), but have been recalculated by Bradbury and Holloway (1988) to a fresh-weight basis.

however, some varieties that are yellow in colour and these contain a significant concentration of β-carotene, up to 1 mg 100 g^{-1} on a dry-weight basis (McDowell and Oduro, 1983).

Cassava leaves, in contrast to the roots, are high in protein (5.1% on a fresh-weight basis, which exceeds 20% on a dry-matter basis). There is therefore much to be gained from the expanded consumption of cassava leaves.

Cassava Cyanogens

Cassava contains cyanogenic glucosides, which, together with their breakdown products (cyanohydrins and free HCN) formed during processing, can cause health problems. Acute intoxication, manifested as vomiting, dizziness or even death, can occur under very rare conditions. Such poisoning occurs when food shortage and social instability induce shortcuts in established processing methods, or when high cyanogen varieties are introduced into an area lacking appropriate processing techniques (Bokanga *et al.*, 1994). It is well established that thiocyanate resulting from dietary cyanide exposure can aggravate iodine exposure deficiency expressed as goitre and cretinism (Bokanga *et al.*, 1994). There is also strong evidence for a causal link between cyanide and the paralytic disease *konzo* (Tylleskar, 1994) and tropical ataxic neuropathy (Osuntakun, 1994). The removal of cyanogens during processing is discussed in the section on small-scale processing.

Cassava varieties are often described as being bitter or sweet. Although the description of bitter and sweet mainly refers to the taste of the raw roots, there is some correlation between high cyanogen/bitter roots and low cyanogen/sweet roots. Concentrations of cyanogens in roots, is however, affected by environmental growth conditions. This means that some varieties generally considered sweet can have a high cyanogenic potential under certain conditions.

Storage and Handling of Fresh Cassava

Postharvest deterioration

Roots as living organs of the plant continue to metabolize and respire after harvest. Cassava's roots are used only to store energy, unlike the roots of sweet potato and yam that are reproductive organs. Despite their agronomic advantages, root crops are far more perishable than the other main staple food crops, the cereals. Once out of the ground, some root crops have a shelf-life of only a few days (Wenham, 1995). There are three main approaches to overcoming the problem of perishability: (i) conventional breeding of varieties with roots having longer shelf-lives; (ii) use of genetic modification to bring about targeted changes in metabolism; and (iii) the use of improved storage techniques. Breeding and genetic modification are long-term strategies, whereas improved storage is likely to have a more immediate impact, but the extent of the improvement will be limited by the roots inherent perishability.

Cassava has a shelf-life that is generally accepted to be of the order of 24–48 h after harvest. Two types of postharvest deterioration are recognized: primary physiological deterioration that involves internal discoloration and is the initial cause of loss of market acceptability, and secondary deterioration due to microbial spoilage (Booth and Coursey, 1974). Physiological deterioration is thought to be a consequence of tissue damage during harvesting. In most cases it is seen as a blue–black discoloration of the vascular tissue referred to as vascular streaking. These initial symptoms are followed by a more general discoloration of the starch-bearing tissue.

Physiological deterioration is a complex process, which is still not fully understood. The process is considered to resemble a typical wounding response in which the healing process is inadequate (Beeching *et al*., 1998). Physiological deterioration shares features of wound responses in other plants: increased activity of enzymes such as phenylalanine ammonia lyase and polyphenyl oxidase, the synthesis of lignin and suberin or secondary metabolites from the phenylpropenoid or terpenoid pathway and the synthesis of free radicals. There is also an accumulation of phenolic compounds, including coumarins, catechins and flavonoids (Buschman *et al*., 2000). The wound healing response is, however, slower than in other crops, but when it does occur, it suppresses physiological deterioration (Wenham, 1995).

Traditional marketing and storage systems have adapted to the perishability of root crops (Wenham, 1995). In the case of cassava, these adaptations range from use of in-ground storage, processing into storable forms at farm level and the general practice of traders is to deal in only small quantities of roots. These ensure that physical losses are minimized. Marketing systems for cassava are also limited by the perishability of the fresh roots and this has financial implications. For example, in Tanzania, delay in getting the crop to market has been reported to be an important factor in determining the level of price discounting at the various stages of marketing. At some stages in the marketing chain, economic losses were greater than 90% of initial value (Fig. 14.1). These economic losses are related to the age of the crop rather than the physical condition of the roots. The perishability of the crop also limits the potential for farmers distant from markets to sell their produce.

Means of overcoming perishability

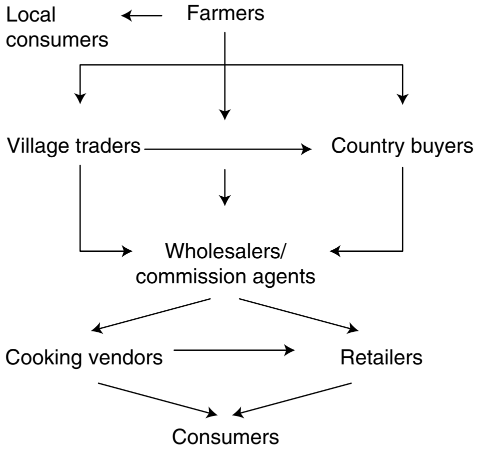
In-ground storage

The simplest means of preserving cassava is to delay harvesting until the crop is needed. This flexibility in harvesting is one of the most important features of the crop when used for food security.

Cassava roots have an optimum harvest age after which there is a loss in yield. At the same time the roots become woody and there can be impairments to flavour (Lancaster and Coursey, 1984). During storage, there is the danger that roots will be infested by pathogens. There is also the problem that this form of storage ties up large amounts of land that could be used to grow other crops. This is a significant problem in densely populated areas (Knoth, 1993).

Traditional storage structures

Knoth (1993) reviewed traditional methods of cassava storage. Roots can be buried in the soil. It is said that this method can be used for storing roots from one season to the next. In West Africa and India, roots that cannot be consumed or processed immediately are piled into heaps and watered daily. Roots can also be coated with a loam paste to attain storage of 4–6 days. Knoth (1993) also mentions the work of Baybay (1981) who tested various traditional methods of storage in the Philippines. He concluded that all the traditional processes tested could only



Level	Age (days)	Discount
Farmer	2	25%
	3	50%
	> 3	> 70%
Country buyer	2–3	80%
	> 3	> 90%
Wholesaler	2–3	75%
	> 3	90%
Retailer	2–3	Up to 50%
	> 3	Negotiable

Fig. 14.1. Fresh cassava marketing chain and levels of losses associated with time delays at different stages (modified from Ndunguru *et al.*, 1998).

prolong shelf-life by a few days. Only storage in trench silos was more successful in extending the storage period.

Improved cassava storage

The Natural Resources Institute (NRI) collaborated with the International Center for Tropical Agriculture (CIAT) to gain an understanding of the process of physiological deterioration (Booth, 1976; Rickard and Coursey, 1981; Rickard, 1985; Wenham, 1995). This research led to an understanding of which storage structures were most effective (Booth and Coursey, 1974; Booth, 1977) and the development of the low-cost storage technique detailed below (Wheatley, 1989).

Initial work focused on the clamp silo. Roots were piled up on a layer of straw in conical heaps weighing between 300 and 500 kg (Rickard and Coursey, 1981). These were covered with straw and soil and openings were left for ventilation. With such a system, it was possible to store roots for up to 4 weeks without significant weight loss or microbial deterioration. The systems required relatively high labour inputs and management of the stores required a degree of experience. These factors may have limited adoption of the system.

Research work on the storage of cassava roots in pits containing sand/soil at 15% moisture content has been conducted in India (Balagopalan, 2000). After 2 months of storage 80–85% of roots were recovered undamaged. Roots lost 15–20% of their starch content after 2 months of storage, which was equivalent to 1 week of storage under ambient conditions. There were also significant reductions in root cyanogen content.

Another method that has been evaluated is the storage of cassava in wooden crates containing damp sawdust. If the sawdust is too moist it promotes fungal growth and if too dry the roots deteriorate quickly. Lining the crates with plastic foil prevents drying out of the sawdust resulting in a storage period of 4–8 weeks (Rickard and Coursey, 1981). The availability and expense of crates, their limited capacity in comparison with the low value and bulky nature of the commodity, together with the high labour requirement of the system, limited its applicability.

The storage of cassava treated with a fungicide in polythene bags was a technique developed by CIAT and NRI. The technique was dependent upon the curing effect of storing roots in polythene bags combined with a fungicide (thiabendazole) to prevent secondary microbial deterioration (Wheatley, 1989). This technique extended the shelf-life from 1–2 days to between 2 and 3 weeks. Although trials with this method were successful in Colombia, it was less successful when it was modified for use in Ghana by

Bancroft and Crentsil (1995). A limitation to adoption of the technology in Ghana was the high costs of polypropylene sacks and the fungicide. For this reason, the polythene bags were replaced with other tightly woven bags such as rice or cocoa sacks and the technology was tested without the use of the fungicide. With these modifications, storage times of 7–10 days were achievable that were adequate for Ghanaian marketing systems (Gallat *et al.*, 1998). The modified technique was evaluated with a number of potential stakeholders and it was found to be particularly useful for local food retailers and itinerant traders. The technique has subsequently been transferred to Tanzania (Westby *et al.*, 1999).

Advanced methods of overcoming physiological deterioration

Refrigeration is not a viable method for preserving cassava in many developing countries, but may be practical for high-value markets. The most favourable temperature for storing fresh cassava is 3°C. At this temperature, the total weight loss after 14 days was 14% and was 23% after 4 weeks (Rickard and Coursey, 1981). Alternatively, roots, or more usually pieces of root, can be stored frozen. Freezing changes the texture making it somewhat spongier, but the flavour is preserved (Rickard and Coursey, 1981). This technique is already used commercially by the world's major exporter of cassava, Costa Rica.

Coating of cassava roots with paraffin wax is another means of extending the shelf-life of fresh roots. This has been done with or without a fungicide. Shelf-lives of up to 2 months have been reported (Knoth, 1993). Waxing is currently the most common way of treating fresh cassava for export.

Varietal selection as a means of overcoming physiological deterioration

Breeding or genetic manipulation are alternative means of overcoming the problem of cassava physiological deterioration. The various approaches were reviewed at an expert consultation at FAO (Wenham, 1995). It was considered that it was possible to use conventional breeding by recurrent selection methods to produce cultivars with resistance to physiological deterioration. However, tremendous efforts would be required to incorporate the trait into different cultivars without altering the characteristics of the parent genotypes.

Genetic manipulation was considered most appropriate to resolve the problem since it should be possible to add new traits to elite genotypes without altering other desired characteristics. Nevertheless, there was no information available on genes involved in the biochemical pathways that are associated with physiological deterioration of cassava. However, because of the their implication in the process of physiological deterioration, the genes and gene products associated with the synthesis and degradation of phenylpropanoids were considered to be the principal targets.

Subsequent work has been carried out on the biochemistry, molecular biology and genetics of physiological deterioration in order to identify potential avenues for its control. Although this has led to more new knowledge on physiological deterioration, there is a need for a concerted global research effort to address the problem.

Small-scale Processing

This section focuses on small scale processing with a specific emphasis on sub-Saharan Africa where processed products are the most important (Table 14.3). This complements the information in chapter 15.

Traditional processing systems

The processing of cassava into more storable forms offers an opportunity to overcome the perishability of the fresh produce. A wide variety of products are produced, especially in Africa and South America. The best overview of the complex nature of cassava processing in Africa has come from the Collaborative Study of Cassava in Africa (COSCA) as described by Nweke (1988). Details of the three most important products in 233 villages in six countries (Côte d'Ivoire, Ghana, Nigeria, Democratic Republic of Congo, Uganda and Tanzania) were collected (NRI, 1992). Across the countries, 147 different product names were used to describe the

623 products for which details were collected. Through a process of examining the key processing steps, this complex array of products was rationalized in eight main groups (Table 14.5; NRI, 1992; Poulter *et al.*, 1992).

Further analysis of the COSCA data (Westby, 1993) has enabled more detailed characterisation of products according to the processing steps involved. This analysis is shown schematically in Fig. 14.2 and is quantified in Table 14.6. Slight discrepancies between Tables 14.5 and 14.6 are due to the more accurate manual form of classification used for the latter table.

Stages in traditional processing

A detailed description of all of the possible cassava products is not possible in this chapter (see Chapter 15). However, some of the key common stages in cassava processing are described below.

Harvesting and transportation of roots

Transportation of cassava roots from the field to the roadside or household is one of the major limitations in postharvest processing. Roots are typically transported in a bowl carried on the head. In some places bicycles are used. The contribution of harvesting and transportation to the labour requirement of processing a mould-fermented cassava product, *udaga*, in Tanzania is shown in Fig. 14.3. Improvements to intermediate forms of transport would have a large impact in many African communities.

Root preparation (peeling, slicing)

Cassava roots are usually peeled prior to processing. Mechanical peelers are not generally available, although technology exists in Brazil for the debarking of cassava roots for the processing of *farinha de mandioca* and extraction of cassava starch (Westby and Cereda, 1994). For many products, peeling is considered one of the most labour intensive processes (see for example Fig. 14.3).

Size reduction (grating)

Size reduction of fresh roots is usually by grating. In many locations in West Africa this is a mechanized process often carried out at a communal facility. There are many designs of grater ranging from punched metal discs to ones that use nails punched through wood. Grating is also a necessary part of starch extraction and similar machines are often used. Where machines are not available, grating is done by hand but this is a very labour-intensive process.

Drying

Sun-dried products are the most common types of processed product in Africa (see Table 14.6). Drying over a fire is practised in some places.

Table 14.5. Product types by country for the first three ranked products in each of 233 villages, COSCA Phase 1.

Product type	Côte d'Ivoire	Ghana	West Nigeria	East Nigeria	Tanzania	Uganda	Zaire	Total	%
Cooked roots	35	20	–	11	9	33	–	108	17
Roasted granules	7	19	18	24	–	–	–	68	11
Steamed granules	30	1	–		–	–	1	32	5
Flours/dry pieces	21	27	17	35	61	52	66	279	45
Fermented pastes	4	10	19	21	1	–	20	75	12
Leaves	–	–	–	–	1	3	2	6	1
Drinks	–	–	–	–	–	6	–	6	1
Sedimented starch	22	–	3	3	–	–	–	28	4
Unclassified	–	5	4	4	2	2	4	21	3
Total								623	100

Note: The figures in the columns indicate the number of times a particular product type was ranked as one of the first three most important in the 233 surveyed villages.
Source: NRI (1992).

One problem of sun drying is that drying times are long. In a study conducted by Wareing *et al.* (2001) on a dried product in Ghana, *kokonte*, it took 7–12 days to dry during the dry season and 8–14 days during the rainy season. Mould growth is common on such products and may be a concern in respect of mycotoxin formation (see pp. 292–293).

Various methods are available for improving drying to produce a better quality product. These include modifications to the size and shape of cassava pieces, use of inclined trays or concrete drying floors (e.g. Best, 1978; Balagopalan, 2000). In Ghana, a system of dried cassava chip production has been developed whereby cassava is chipped into small pieces using a machine developed by the International Institute of Tropical Agriculture (IITA) in Nigeria (Jeon and Halos, 1991). The combination of the chipper, drying on raised trays for 1 day and on polythene sheeting for 1 day produces high-quality product at minimum cost (Westby and Gallat, 1999).

Fermentation of cassava

Fermentation is an important processing technique for cassava, especially in Africa. Three major types of fermentation are recognized: the grated root fermentation, fermentation of roots under water and mould fermentation of roots in heaps.

The grated root fermentation method is important in the processing of many West African products including the roasted granules (*gari*), steamed granules (*attieke* from Côte d'Ivoire) and some of the fermented pastes (*agbelima* and *placali* from Ghana and Côte d'Ivoire respectively). Typically grated roots are allowed to ferment in sacks for 3–5 days, which encourages a lactic acid fermentation and a

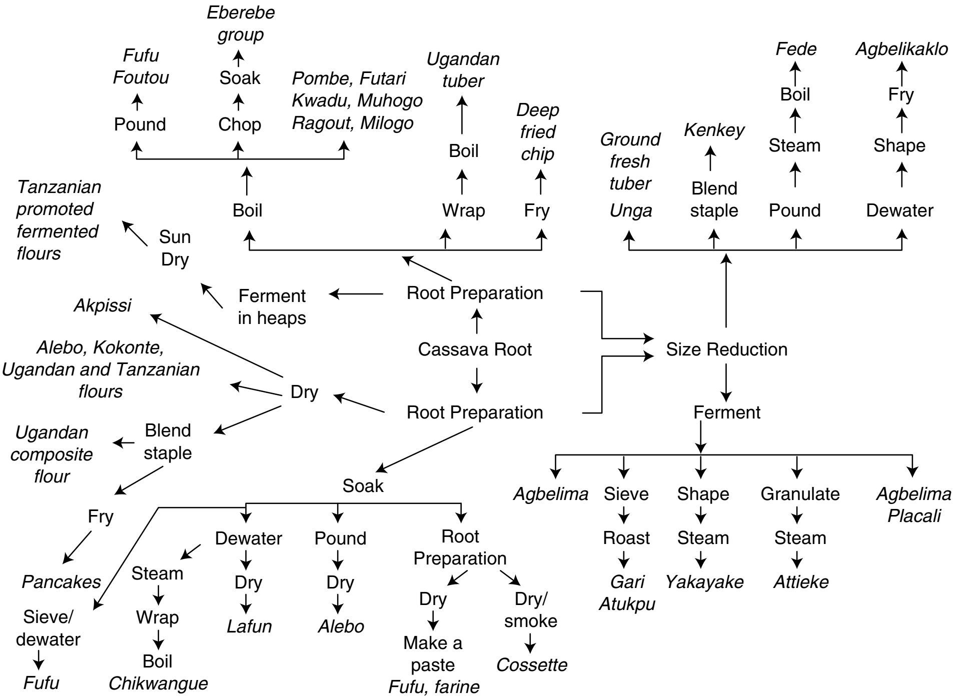


Fig. 14.2. Interrelationship of cassava products from 233 villages in six African countries (Henry *et al.*, 1998).

Footnote for Table 14.6 opposite

[a] The number after the number of villages ranking the product third is the number of villages where the ranking was not recorded.

Table 14.6. Distribution of cassava products using the categories provided in Table 14.5 and Fig. 14.2.

Product group/ product type	No. of alternative names	Country	No. of villages where ranked			Total no. villages (% of surveyed in country)
			1st	2nd	3rd[a]	
1. Fresh roots						108
Ererebe group	6	Nigeria	0	1	10	11 (18%)
Foutou/fufu	2	Côte d'Ivoire	16	9	6 + 1	32 (80%)
	1	Ghana	10	3	2	15 (50%)
Tuber	12	Uganda	29	2	0	31 (97%)
Other		Various				19
2. Roasted granules						78
Gari	2	Côte d'Ivoire	1	2	4 + 1	8 (20%)
		Ghana	7	13	2	22 (73%)
		Nigeria	25	22	1	48 (79%)
3. Steamed granules						35
Attieke	1	Côte d'Ivoire	15	12	7	34 (85%)
Others	1	Ghana				1
4. Dried flours/pieces						267
Acid soaked						
Alebo	6	Nigeria	21	1	3	25 (40%)
Cossette	1	Zaire	15	16	0	33 (92%)
Fufu	2	Zaire	7	12	7 + 4	30 (83%)
Lafun	1	Nigeria	2	6	4	12 (20%)
Others	3	Nigeria				6
Air dried						
Alebo	5	Nigeria	10	1	2	13 (20%)
Kabalagala	2	Uganda	0	7	4	11 (34%)
Kokonte	2	Ghana	9	8	11	28 (93%)
		Côte d'Ivoire	3	8	5 + 2	18 (45%)
Cassava flour (Tz)	12	Tanzania	6	10	5 + 7	28 (93%)
Cassava Flour (Ug)	5	Uganda	0	14	7	21 (66%)
Composite flour	5	Uganda	1	5	2	8 (25%)
Others	2	Various				5
Mould fermented						
Tanzanian		Tanzania	12	5	3 + 8	28 (93%)
Others	1	Uganda				1
5. Fermented pastes						47
Grated roots						
Agbelima	2	Ghana	3	3	3 + 1	10 (33%)
Placali	2	Côte d'Ivoire	4	8	11	23 (58%)
Soaked roots						
Akpu (fufu)	6	Nigeria	8	13	19	40 (63%)
Chikwangue	3	Zaire	12	2	5 + 5	24 (64%)
6. Products from leaves						
Total	5	Zaire, Ug, Tz				7
7. Drinks						
Total	14	Zaire, Uganda				22
8. Sedimented starches						
Starch	1	Nigeria	0	2	2 + 1	5 (8%)
9. Unclassified						
Total	5					5

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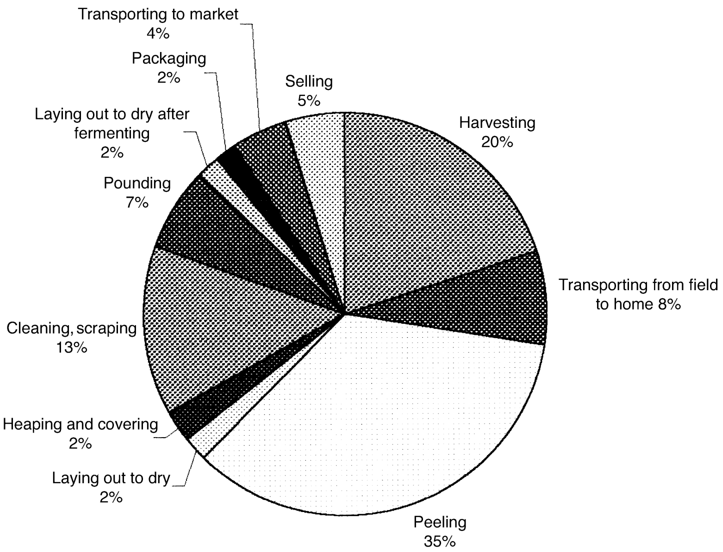

Fig. 14.3. Estimated distribution of labour during the household level processing of *udaga*, a heap-fermented cassava product in Tanzania (from van Oirschot *et al.*, 2001).

consequent reduction in pH value to less than 4.0. Starter cultures are only common in Côte d'Ivoire where some pre-mould fermented roots are added during grating. This is said to improve smoothness. Although there is probably a succession of organisms, the grated root fermentation is dominated by lactic acid bacteria (Okafor, 1977; Abe and Linsay, 1978; Ngaba and Lee, 1979).

Fermentation of cassava roots under water is conducted across Africa from Sierra Leone to Tanzania. A variety of products are produced including wet paste (such as *akpu*, *fufu* or *chikwangue*) and dried flours (such as *lafun*). Roots are soaked in water with or without peeling for typically 3–5 days. The fermentation causes the roots to soften (Westby and Choo, 1994) which means that they can be easily broken up by hand into small pieces and sun dried or passed through a sieve to remove fibre, leaving a smooth paste. At the start of the fermentation there is a mixed microbial flora consisting of *Bacillus* spp., *Leuconostoc* spp., *Klebsiella* spp., *Corynebacterium* spp., *Lactobacillus* spp., *Aspergillus* spp., *Candida* spp. and *Geotrichum* spp. The final fermentation is, however, dominated by lactic acid bacteria and yeasts (Oyewole and Odunfa, 1988). *Clostridium* is thought to be the origin of butyrate, which imparts a typical odour to the product (Brauman *et al.*, 1995). They may also play other roles such as the production of pectic enzymes and this deserves further investigation.

Heap fermented cassava products are produced in Tanzania (Ndunguru *et al.*, 1999), Uganda and Mozambique (Essers, 1995). This type of fermentation is achieved by heaping peeled roots and leaving them to ferment naturally. Essers and Nout (1989) reported the isolation of *Rhizopus* spp., *Mucor* spp., *Penicillium* spp. and *Fusarium* spp. Studies in Tanzania (M.N. Kendall, personal communication) have indicated that *Rhizopus* spp., *Neurospora sitophilia* and *Penicillium* spp. can be isolated from the *udaga* fermentation. Market studies in the Lake Zone of Tanzania have indicated that different moulds can have an impact on the value of the commodity. Ndunguru *et al.* (1999) reported that visible mould is disliked, but some types of mould were disliked more than others. Average valuation discounts are 10–15% for orange-coloured mould, 20–25% for green-coloured mould and 35–40% for black-coloured mould.

Cyanogen removal during processing

The cyanogenic glucosides present in fresh cassava roots are linamarin (93%) and lotaustralin (7%) (Nartey, 1978). Linamarin is stored in the

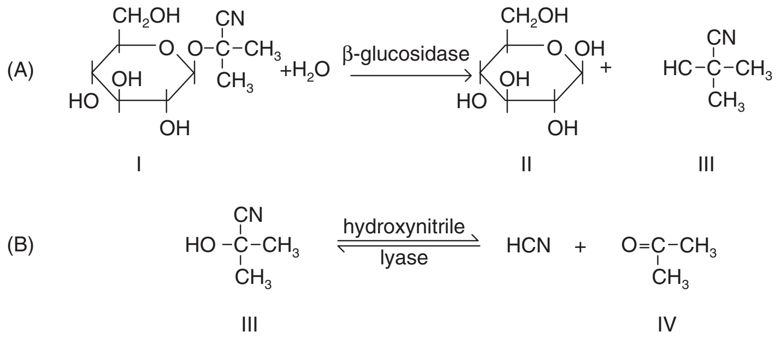

Fig. 14.4. Enzymatic breakdown of linamarin, Compound 1 (from Conn, 1994). Compound III, (acetone cyanohydrin) also breaks down at a rate dependent upon pH and temperature.

vacuoles of the cassava cells (McMahon *et al.*, 1995). It is hydrolysed to the corresponding ketone (acetone cyanohydrin) and glucose by the endogenous enzyme, linamarase (Fig. 14.4), when cellular damage occurs (de Bruijn, 1973; Nartey, 1978). Linamarase is situated in the cell wall (Mkpong *et al.*, 1990) physically separated from linamarin. Cyanohydrins breakdown non-enzymically at a rate dependent upon pH and temperature (Cooke, 1978), with their stability increasing at acidic pH values (Fig. 14.4). Acetone cyanohydrin can also be broken down by an enzyme hydroxynitrile lyase (HNL), but it has been demonstrated that expression of the HNL gene is mainly in the leaves with little activity in the roots (White *et al.*, 1998).

The low levels of HNL expression in the roots is very significant to the medical condition *konzo*. Tylleskar *et al.* (1992) have shown that certain processed flours contain high levels of acetone cyanohydrin, but little linamarin or HCN. The low activity of HNL in the roots will contribute to this accumulation.

Chemically linamarin is stable, soluble in water and resists boiling in acid. Acetone cyanohydrin is also soluble in water and has a boiling point of the order of 82°C. Free HCN is volatile at 25.7°C and so is rapidly volatilized at tropical ambient temperatures.

Efficient processing to ensure that cyanogens are reduced to a safe level is based on the above knowledge. The essential features of good processing are sufficient tissue disruption to allow endogenous linamarase to react with linamarin and then favourable conditions for the breakdown of acetone cyanohydrin, or, conditions under which the compound will volatize spontaneously. It was the development of an assay method for the different cyanogenic compounds (Cooke, 1978, modified by O'Brien *et al.*,1991 and later by Essers *et al.*,1993) that allowed the mechanisms of cyanogen reduction during processing to be elucidated.

The production of the Nigerian product *gari* (similar to *farinha de mandioca* in Brazil) is an example of efficient cassava processing. Processing involves the grating of peeled roots, holding of the roots at ambient temperature to facilitate fermentation. Water is squeezed out of the fermented material to bring the moisture content down to 50%. The final product is roasted to form a granular dried product. The changes in cyanogens during the *gari* fermentation were investigated by Vasconcelos *et al.* (1990). Plant and microbial enzymic activities were distinguished by comparing a natural fermentation with irradiated grated root material incubated under the same conditions. In both cases, more than 95% of the initial linamarin content was hydrolysed within 3 h of grating (Fig. 14.5). Grating is therefore important for bringing linamarin into contact with linamarase. Significant concentrations of cyanohydrin and free HCN were left in the paste after fermentation. The cyanohydrin is stable under acidic conditions and it is now known that roots lack hydroxynitrilase activity.

Assuming efficient grating and an acceptable level of endogenous enzymatic activity, linamarin reduction is not the constraint and so processing has to be geared to reducing the concentrations of cyanohydrin and free HCN. In

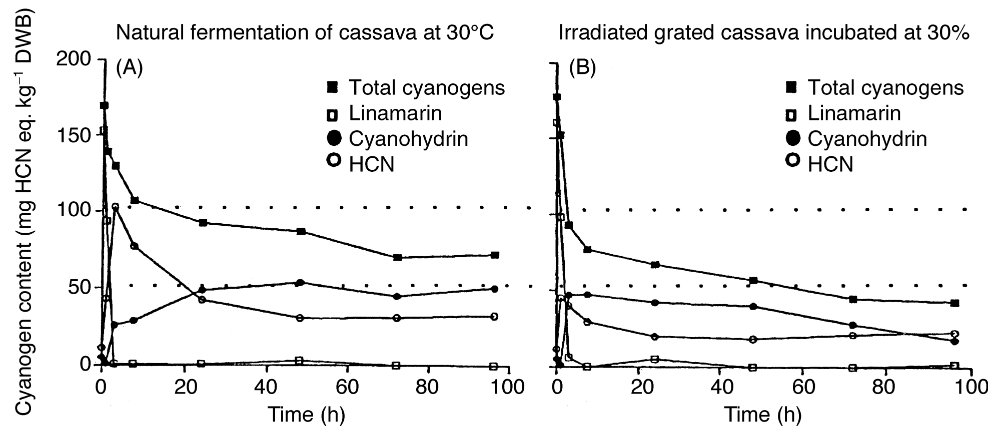

Fig. 14.5. Changes in cyanogens during the fermentation of grated cassava and incubation of grated irradiated cassava at 30°C. Roots were grated at 0 h. The effects of roasting the product are not shown (Westby and Choo, 1994).

the case of *gari* processing, roasting is efficient at volatilizing HCN and cyanohydrin leaving low residual concentrations (HCN 3.4 mg CN equivalents kg^{-1} and cyanohydrin 2.2 mg CN equivalents kg^{-1} on a dry-weight basis in the natural fermentation).

Where roots are soaked in water, the fermentation enables softening of the roots which has the combined effect of enabling linamarin and linamarase to mix and also to enable leaching of the cyanogens (Westby and Choo, 1994). The efficiency of these processes and of any post-fermentation processes in reducing cyanogens dictates the safety of the product. For dried products the efficiency of drying is important to ensure that most of the residual cyanogens are volatilized.

In the case of the heap-fermented products, microbial growth contributes to cyanogen reduction by softening the cassava roots which enhances the contact between endogenous linamarin and linamarase (Essers, 1995). The efficiency of subsequent drying is important to ensure volatilization of residual cyanogens.

Storage of Dried Cassava Products

Dried cassava products are intrinsically more stable than fresh roots. Their deterioration is caused primarily by exogenous factors such as fungi, bacteria, insects and rodents (McFarlane, 1982). Fungal deterioration is discussed later in respect of mycotoxin formation.

Insect infestation of dried cassava is the most important form of damage and well dried products are unable to support microbial growth. A wide range of insect species have been associated with dried cassava products and these were reviewed by McFarlane (1982). A significant problem of stored cassava is *Prostephanus truncatus* (Horn), the larger grain borer. It was introduced into Africa in the 1970s and has become a major pest of both cassava and maize (Hodges, 1986). Losses in Togo from the pest have been estimated at up to 30% after 6 months of storage (Wright, 1993).

Parker *et al.* (1981) suggested that standards and practices similar to those applied to cereal grains should be used for dried cassava since the spectrum of infestation is similar.

Mycotoxin Contamination of Cassava Products

Fungal growth is common on dried cassava products (Clerk and Caurie, 1968; Essers and Nout, 1989; Jonsyn, 1989), especially in Africa where this class of processed product is the most common. Fungal growth occurs at three stages in processing: during slow drying, during storage under humid conditions, or in some specific products that are fungally fermented. When growth of potentially mycotoxigenic fungi occurs, there is the possibility of mycotoxin formation. Mycotoxins are extracellular zootoxic metabolites (exotoxins) produced by filamentous fungi (moulds) in foods consumed by man or animals.

A number of potentially mycotoxigenic storage fungi have been isolated from cassava, for example: *Aspergillus flavus* (Clerk and Caurie, 1968; Shank *et al.*, 1972; Mota and Lourenco, 1974; Masimango *et al.*, 1977), *Aspergillus ochraceus* (Masimango *et al.*, 1977), *Aspergillus versicolor* (Clerk and Caurie, 1968) and *Penicillium* spp. (Clerk and Caurie, 1968; Mota and Lourenco, 1974). The potential mycotoxin risk associated with this contamination has not been fully assessed. Mycotoxin contamination of cassava has been documented (Mota and Lourenco, 1974; Brudzynski *et al.*, 1977; Constant *et al.*, 1984; Sajise and Ilag, 1987), although the findings have not always been subjected to confirmatory tests.

Scopoletin, a coumarin compound, can accumulate in cassava roots during postharvest physiological deterioration (Wenham, 1995). It fluoresces in a similar way and has a similar Rf to aflatoxin B_1 in some common thin layer chromatography (TLC) systems. It is therefore possible that some reports of aflatoxin contamination of cassava chips may instead be due to the presence of scopoletin (Wheatley, 1984). Reports in which the presence of aflatoxin has not been confirmed, or scopoletin not removed, should be treated with caution. Other mycotoxins have been reported. For example, zearalenone in cassava meal from Indonesia and Thailand, at 90 $\mu g\ kg^{-1}$ and 3 mg kg^{-1} respectively (Bottalico *et al.*, 1980) and ochratoxin A in two out of 33 samples of cassava flour from Brazil, 32 and 65 $\mu g\ kg^{-1}$ respectively (Soares and Rodriguez-Amaya, 1989).

In a recent study of dried cassava in Ghana (Wareing *et al.*, 2001), 125 households in 19 villages producing dried cassava products were interviewed. Mould growth during processing or storage was a problem during June and July, the rainy season. Most producers and market traders preferred non-mouldy *kokonte* (the dried cassava product), although many (59%) would consume a mouldy product. There was a price premium for non-mouldy *kokonte*. The most commonly isolated microorganisms were yeasts and *Cladosporium* spp. (44 out of 49 samples). Other fungi isolated included *Aspergillus* spp. (20 samples), *Penicillium* spp. (15 samples) and *Fusarium* spp. (30 samples). Sterigmatocystin was detected in ten samples at 0.17–1.67 mg kg^{-1}; patulin in four samples at 0.55–0.85 mg kg^{-1}; cyclopiazonic acid in four samples at 0.08–0.72 mg kg^{-1}; penicillic acid in five samples at 0.06–0.23 mg kg^{-1} and tenuazonic acid in three samples at 0.02–0.34 mg kg^{-1}. The authors concluded that mycotoxin contamination of mouldy cassava was a potential problem and improvements in processing were necessary to improve the speed of drying in order to avoid mould growth.

Mould growth on fermented cassava products has so far not been associated with mycotoxin formation. Essers (1995) reported that in his investigation of the solid substrate fermentation of cassava in Uganda, the Ames test for mutagenicity and cytotoxicity was negative in all of the tested flours and aflatoxins were absent in ten screened samples.

Development of Cassava Processing Beyond Household Scale

There is a progression of cassava processing at the small-scale level beyond traditional products that starts at the production of high-quality flour, chips and eventually starch and starch products.

Commercialization of traditional products

Traditional products can themselves be scaled up. This can be done in several ways, but the most common is to focus an enterprise around a machine (a grater or mill). This is common for *gari* processing. Individual unit operations, such as peeling, sieving or roasting of *gari* are carried out in a similar way to that at household level. The only difference is that hired labour may be brought in to do the tasks. Also common are situations were groups of people, often women, come together to market a processed commodity.

Attempts have been made to produce *gari* on a larger scale, but have not always been successful because of problems of raw material supply and in producing a product that is competitive with that produced at the household/small enterprise level.

The situation is different in Latin America where traditional *farinha de mandioca* (cassava flour prepared by toasting grated cassava) processing and *polvilho azedo* (fermented cassava starch) have been scaled up and in many cases are mechanized.

Some forms of commercialization require a modified product. Sanni *et al.* (1998) in their analysis of the current state of *fufu* (a wet fermented paste) processing concluded that if the product is to compete with *gari*, a dried form of the product is required that will appeal to urban consumers.

Accessing new market opportunities – using cassava flour to replace wheat flour

In broad terms, there are three major new market opportunities that farmers and processors can access. These are high quality cassava flour as a replacement for wheat flour, cassava starch as a raw material for food and non-food industries and cassava chips for either the domestic livestock feed sector or for export (Bokanga, 1995). In addition, cassava flour or starch can be further processed to serve as a raw material for sweeteners, ethanol, etc. (see Chapter 15). These market opportunities, when developed, provide new outlets for farmers' produce. In some cases, through on-farm processing, value is added to the commodity before it is sold into the marketing system.

Cassava flour is common in Africa and, provided the quality is good, there is potential to substitute wheat flour in a number of products including bread, biscuits and cakes. Ouraga-Djoussou and Bokanga (1998) have shown that, with a 15% substitution rate of wheat flour with cassava, Nigeria could save up to US$14.8 million in foreign exchange annually. US$12.7 million would go to cassava processors and US$4.2 million to cassava farmers. Bokanga (1998) summarizes the use of cassava flour in bread. He cites a recent survey in Nigeria and Côte d'Ivoire where it was shown that the majority of the bread consumed in the survey area was from composite flour (wheat mixed with cassava, sorghum or maize flour).

In order to address a need to diversify the range of cassava products in Tanzania, bakery products made from cassava instead of wheat (doughnuts, cakes, biscuits, croquettes and chinchin) that had been developed at IITA (Onabolu *et al.*, 1998) were evaluated. Kapinga *et al.* (1998) adopted a cautious approach to the dissemination of these products in the Lake Zone. This involved the following stages: (i) identification of the initial need to diversify cassava utilization; (ii) a feasibility study; (iii) an interactive pilot phase where information was obtained on the factors that would facilitate sustainable uptake of the technology; and (iv) a wider dissemination phase.

There was potential for some new products, but not for others. This was reflected in the high take-up rates in both the pilot and wider dissemination phases of only certain products. The most effective dissemination route for these products was through church and women's groups and it was necessary to provide technical support during adoption of the technology (Kapinga *et al.*, 1998). Returns to labour investment when using cassava were significantly improved (Kapinga *et al.*, 1998).

Cassava as a Spur for Rural Development

As indicated in this chapter and elsewhere in this book, cassava is important to the livelihoods of many poor people in the world. This importance is largely a consequence of cassava's agronomic advantages, particularly its high yield of carbohydrate even on poor soils, good tolerance to drought, is relatively resistant to pest infestation and disease, and because it can be stored in the ground until required (DGIS, 1991).

If cassava's contribution to poverty alleviation is to be enhanced, improvements have to made in the postharvest sector. The best way of making any improvements is a subject of much debate, but clearly with limited resources, means have to be found to ensure interventions have the maximum impact. Reasons for introducing improvements to existing systems include: enhanced financial returns through more efficient processing or a higher quality product, introduction of a new product to meet a market opportunity, reduced drudgery or reduced environmental impact. To conclude this chapter, we consider two specific but complementary approaches: use of ‘needs assessment’ and the use of a ‘demand driven’ approach as proposed in the Global Cassava Development Strategy.

The use of needs assessment

Informal needs assessment (NA) is a term used to describe a range of qualitative diagnostic methods such as rapid rural appraisal and participatory rural appraisal (Cropley and Gilling, 1993). Overviews of participatory research approaches are given by Chambers (1992) and Chambers and Gildyal (1985). Their essence is that they facilitate scientists to allow farmers to participate in the formulation of the research agenda. A common criticism of previous post-harvest research, and indeed agricultural research in general, is that technical innovation has been high, but adoption has been poor. The use of NA can improve this situation by actively involving beneficiaries in the key phases of the project or research and development cycle in which priorities for research are set or in which technology choices are made. By ensuring the relevance of research and subsequent technical interventions, the prospects for adoption, and therefore impact, are greatly improved.

The tools used in NA include: review of secondary information, direct observation, semi-structured interviewing, scoring, ranking, diagramming and the use of case-studies. The techniques are described in detail in Kleih *et al.* (1997). It is not necessary, or even in many cases desirable, to use all of the tools in all circumstances. The tools should only be used as means to facilitate a dialogue between scientists and those involved in the system. As in all scientific research, hypothesis formulation and testing are central and take place through an iterative process of discussion and explanation.

NA has been used for a number of years to target technical interventions. Examples of how the techniques have been used are described in Westby *et al.* (1998).

Demand-driven approach as proposed in the Global Cassava Development Strategy

A Global Cassava Development Strategy (Plucknett *et al.*, 2000) was validated at an international forum in 2000. The strategy presents a vision that cassava will spur rural industrial development and raise incomes for producers, processors and traders and it will contribute to the food security status of its producing and consuming households. The essence of the strategy is to use a demand-driven (market-orientated) approach to promote and develop cassava-based industries with the assistance of a coalition of groups and individuals interested in developing the cassava industry.

The strategy consists of identifying, in a systematic manner, the opportunities and constraints of cassava at each level of the supply chain. This can be done by groups and individuals interested in developing the cassava industry – producers, processors and consumers of cassava – as well as associated national, international and non-governmental organizations (NGOs). Concepts of business development and management as well as international economic cooperation are important tools in implementing the strategy. Scientific support is also essential to help overcome important problems within the production–processing–marketing continuum. Adaptive research is also important to ensure that existing and evolving knowledge is harnessed in an appropriate and useful fashion.

The strategy suggests the utilization of ‘industry analysis’. Industry analysis consists of identifying, in a systematic manner, the opportunities and constraints at each stage of the supply chain. Industry analysis involves stakeholders in a participatory effort to identify strengths, weaknesses and opportunities. Industry analysis is a demand-driven approach to technical change through:

1. Explicitly considering stakeholders as equal partners in determining the needs and future plans for a dynamic cassava industry.
2. Building a practical, shared vision for cassava development.

3. Helping make action plans for the industry, including the who, what, why, and how, plus the question, with whose money?
4. Building better linkages with private sector organizations.
5. Better links with and among public-sector institutions.
6. Co-stewardship of research and service outputs with users.
7. Rapid introduction of high-impact technologies through public and private sector partnerships.

The initiation of this strategy will require 'catalysts' capable of identifying marketing opportunities, and bringing these to the attention of stakeholders and 'champions', capable of providing support and resources for the growth and development of cassava markets. Even if the stakeholders agree that there is a growth market for cassava, there may still be need for research and development, provision of infrastructure and investments, and changes in policies to grasp the new opportunity.

A necessary first step in the development of a market-driven global cassava strategy is the identification of markets that are growing or could potentially grow. A second step is the provision of a consistent supply of a relatively uniform product. A third step, related to step two, is to provide the market with a competitively priced product that meets the consumers' requirements. A fourth step is to secure the cooperation of those associated with the market opportunity.

The development path for cassava will be product, location and time specific. Nevertheless, it would appear that if the market growth potential exists because of a structural change in the economy (e.g. decreasing number of farmers and increasing number of urban consumers of cassava products, resulting in market growth) it would be expected that NGOs and national governments would be in the best position to act as champions and catalysts. If, on the other hand, the market growth exists because cassava is price competitive then both national and international agencies may act as champions and catalysts.

The Global Strategy should be seen as comprising both 'bottom–up' and 'top–down' approaches. It is an amalgamation of national, regional and continental strategies and plans, augmented by global efforts to identify and stimulate markets. The national efforts will be the action-sites for implementing the global strategy by undertaking specific investment projects. The global effort assists through the promotion and diffusion of vital product, market and technological information (as a global public good). Moreover, at the global level, the validated strategy will be promoted to key players in both private and public sectors (industries, governments, finance and development agencies, etc.).

Conclusion

In this chapter the use of cassava as food, and aspects of storage and small-scale processing have been considered. The perishability of fresh cassava means that postharvest interventions are probably more important than for any other crop. Although there has been an emphasis on the technical side of storage and processing, it can be seen that if practical interventions in cassava postharvest systems are to have an impact, there is a need for a multi-disciplinary approach. Whatever the approach, it has to be demand/needs driven and be economically viable. In this way, cassava can be a spur to rural development.

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