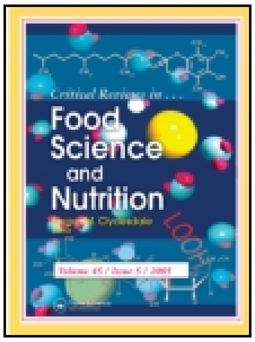

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Cassava (*Manihot esculenta* Crantz) and Yam (*Dioscorea* spp.) Crops and Their Derived Foodstuffs: Safety, Security and Nutritional Value

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*Cassava (*Manihot esculenta *Crantz) and yam (*Dioscorea spp.*) are tropical crops consumed by ca. 2 billion people and represent the main source of carbohydrate and energy for the approximately 700 million people living in the tropical and sub-tropical areas. They are a guarantee of food security for developing countries. The production of these crops and the transformation into food-derived commodities is increasing, it represents a profitable business and farmers generate substantial income from their market. However, there are some important concerns related to the food safety and food security. The high post-harvest losses, mainly for yam, the contamination by endogenous toxic compounds, mainly for cassava, and the contamination by external agents (such as micotoxins, pesticides, and heavy metal) represent a depletion of economic value and income. The loss in the raw crops or the impossibility to market the derived foodstuffs, due to incompliance with food regulations, can seriously limit all yam tubers and the cassava roots processors, from farmers to household, from small-medium to large enterprises. One of the greatest challenges to overcome those concerns is the transformation of traditional or indigenous processing methods into modern industrial operations, from the crop storage to the adequate package of each derived foodstuff.*

Keywords Cassava, yam, food safety, food security, tropical crops

1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz), also known as manioc, mandioca, or yucca in South America, or tapioca in Asia, is one of the leading food and feed plants in the world. The roots are a staple food that provides carbohydrates and energy for more than 2 billion people in the world, while representing the main source of carbohydrate and energy for the approximately 700 million people living in the tropical and sub-tropical areas (Montagnac et al., 2009a). Cassava ranks fourth among staple crops, after rice, sugar, and corn/maize, with a global production of about 183 million ton per year (FAOSTAT, 2011). The crop originated in South America (Brazil and Paraguay); currently it is grown in more than 90 countries and has a total cultivation area of ca. 16.5 million hectares (FAOSTAT, 2011). The majority of it is harvested in three regions: West Africa and the Congo basin, which account for 85% of the total cultivation area, tropical South America, and South East Asia (Kawano, 2003), where Africa and Asia contribute for more than 70% of the cassava harvest (El-Sharkawy, 2003). Cassava is to African population as rice is for the Asian one, or wheat and potatoes are for the European people. Indeed, in Western countries, cassava is not commonly used and mainly because of the presence of toxic compounds (Montagnac et al., 2009). Cassava has also a higher yield (and carbohydrate) per hectare than the main cereal crops and can be grown at a considerably lower cost. For instance, fresh cassava root has a yield of 71 ton/hectare (daily 250 Kcal/hectare); the yields for rice and what grain, on the other hand, are 26 ton/hectare (daily 156 Kcal/hectare) and 16 ton/hectare for wheat grain (daily 110 Kcal/hectare), respectively (El-Sharkawy, 2003). Cassava can grow at suboptimal conditions; it is tolerant to

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soil infertility and drought stress, it can be stored underground for several months after maturation without water and still retains its nutritional value (Ukwuru and Egbonu, 2013).

Regarding yam (*Dioscorea* spp.), the tuber is a valuable source of carbohydrate for people of the tropical and subtropical Africa, Central and Southern America, parts of Asia, the Caribbean, and Pacific Islands (Ojoko and Gabriel, 2010). It originated in the Far Est and spread westward. Today is one of the most highly regarded food products in tropical countries of West Africa, which is the principal producer on a global basis and where is closely integrated into social, economic, cultural, and religious aspects of communities (Okigbo and Ogbonnaya, 2006). In Africa, yam is the second most important crop after cassava, with a production reaching under one third the level of the root, ca. 57 million tons (FAOSTAT, 2011a). Although more than 600 species of the tuber exist, only few are important and include white yam (*Dioscorea rotundata*), yellow yam (*D. cyaenensis*), water yam (*D. alata*), trifoliate yam (*D. dumetorum*), and Chinese yam (*D. esculenta*) (Gbolagade et al., 2011). More than 95% (2.8 million ha) of the current global area under yam cultivation is in Sub-Saharan Africa, with a mean gross yields of 10 ton/hectare (Akissoe et al., 2003). Nigeria is known to be the largest producer of yam in the world; annual production in the country is estimated at ca. 37 million ton (FAO, 2011a) and the crop is crucial for food security and poverty reduction; indeed, the average consumption of yam in Nigeria, including by-products generation, is estimated in the range 0.5–1 kg/day/person (Foraminifera Market Research, 2012). The cultivation of this tuber is really very important since serves as a source of income generation to peasant farmers and for the laborers working on yam farms as well as for those engaged in its sale (i.e., the itinerant traders who assemble the crop from village to village, the urban center marketers who retail the commodity (Akanji et al., 2003)).

Despite the importance of these crops, there are currently serious issues associated with their production and consumption. High post-harvest losses are registered, mainly in the production of yam (Opara, 2006); considering food safety, the presences of toxic compounds in cassava and the presence of harmful contaminants in both crops are a cause of concern. The availability of safe food is a prerequisite for the well-being of people and for the development of national economies. The low quality and safety of food have a significant impact on human and animal health, and are a major constraint to export trade. Therefore, the objective of this revision is to present an overview on the most important aspects of cassava and yam production and related to the nutritional value as well as to the food safety and food security.

2. CASSAVA

2.1 Nutritional Value

Cassava roots are a good source of energy while leaves provide protein, vitamins, and minerals. The roots contain 0.1–0.5% crude fat on fresh weight (FW), 1–3% crude proteins, and 80 to 90% carbohydrate on dry weight (DW), of which 80% is starch and remaining small quantities of sucrose, glucose, fructose, and maltose. Carbohydrates content in cassava is higher than in potatoes and less than in wheat, rice, yellow corn, and sorghum. About 50% of crude protein consists of whole proteins while remaining 50% are free amino acids, mainly glutamic and aspartic acid (Gil and Buitrago, 2002). Cassava roots provide ca. 140 Kcal/100 g (Oke, 1990). Compared to leaves, roots have very low quantities of lipids, minerals, proteins, and vitamins; leaves in fact have a crude protein content of 5–7%, 1–2% crude fat, 2% minerals (DW), and a well-balanced amino acid profile comparable to white, fresh egg, with the exception of methionine, lysine, and isoleucine (Montagnac et al., 2009). The essential amino acid profile provided by cassava leaves is higher than that of the protein daily intake recommended by the Food and Agriculture Organization's (FAO) and higher than the soybean protein (FAO/WHO, 1973; Okigbo, 1980; West et al., 1988). Cassava leaves are rich in iron, zinc, manganese, magnesium, and calcium; moreover, vitamins B1, B2, and C, where carotenoids are also present (Eggum, 1970; Adewusi and Bradbury, 1993; Wobeto et al., 2006). On the other hand, cassava roots and leaves have a huge deficit of the sulfur-containing amino acids such as methionine and cysteine, and nutrients are not well allocated in the plant (Gil and Buitrago, 2002). Proximate composition of cassava root and leave is reported in Table 1. Cassava also contains antinutrients, such as phytate, fiber, nitrate, polyphenols, oxalate, and saponins; all these compounds can have either positive or adverse effects on health, depending upon the amount ingested. Although some of these compounds act as antioxidants and anticarcinogenic, they can also interfere with nutrient absorption and utilization, and may have toxic side effects (Wobeto et al., 2007). Overall, a cassava meal can provide complete dietary needs in terms of calories, protein, minerals, and vitamins only if cassava leaves are added to the root along with another source of essential sulfur-containing amino acid-rich protein.

Apart from nutrient, cassava contains some endogenous unsafe compounds, and can acquire contaminants during cultivation and processing into foodstuffs. Therefore, the risks correlated with the consumption of the root can be classified into two categories: risk associated with harmful substances present in the crop itself, and risks associated with processing and product development. In the following section food safety concerns are discussed.

Table 1 Composition of cassava roots and leaves (Bradbury and Holloway, 1988; Montagnac et al., 2009) and yam tubers (Oke, 1990; Bhandari et al., 2003; Polycarp et al., 2012)

Composition	Cassava root (100 g)	Cassava leave (100 g)	Yam tubers (100 g)
Caloric content (Kcal)	110–150	90	80–120
Water (g)	46–85	65–89	58–80
Protein (g)	0.3–3.5	1–10	1.5–6
Lipid (g)	0.03–0.5	0.2–2.9	0.1–0.2
Carbohydrates (g)	25–36	7–18	15–38
Fiber (g)	0.1–3.7	0.5–10	0.6–3.5
Ash (g)	0.4–1.7	0.7–4.5	1.3–7.5
Vitamin			
Ascorbic acid (mg)	15–50	60–370	–
Niacin (mg)	0.6–1.1	1.3–2.8	0.07
Riboflavin (mg)	0.03–0.06	0.21–0.74	0.04
Thiamin (mg)	0.03–0.28	0.06–0.31	0.10
Vitamin A (μg)	5–35	8300–11800	–
Minerals			
Calcium (mg)	19–176	34–710	6.5–116
Copper (mg)	0.2–0.6	0.3–1.2	0.1–0.4
Iron (mg)	0.3–14	0.4–8	1.5–9
Magnesium (mg)	30–80	120–420	40–83
Manganese (mg)	0.3–1	7–25	0.95–3
Phosphorous (mg)	6–150	27–210	40–160
Potassium (mg)	250–720	350–1230	250–1500
Sodium (mg)	76–210	50–180	63–100
Zinc (mg)	1.4–4	7–25	5.4–7.8

2.2 Cyanides

Cyanide is the most toxic factor restricting the consumption of cassava roots and leaves; indeed, this is the main reason why cassava is not commonly consumed in Western countries (Montagnac et al., 2009). Cassava contains cyanogenic glucosides that are toxic for humans and which can lead to serious health disorders. The crop contains potentially toxic levels of cyanogenic glucosides in form of linamarin (95% of total cyanogen content) and lotaustralin (5%). Linamarin is present in all cassava tissues (Balagopalan et al., 1988; Bokanga, 1994, 1994a) and it is synthesized from the amino acid valine. In particular, cassava's bitter varieties have a cyanide level exceeding the Food and Agriculture Organization/World Health Organization (1991) recommendation of 10 mg/kg DW, which makes cassava acutely toxic for humans.

Cyanogenic glucosides are present in leaf, stem, root peel, and root parenchyma (peeled root); the leaves have a cyanogenic potential 5 to 20 times higher than that of the peeled root. Cyanide content ranges from 53 to 1300 mg HCN (hydrocyanic acid) equivalents/kg DW (Wobeto et al., 2007) in leaves, and from 10 to 500 mg HCN equivalents/kg DW (Siritunga and Sayre, 2003) in peeled root. Consumption of 50 to 100 mg/day of cyanide has been associated with acute poisoning and has been reported to be lethal for adults (Montagnac et al., 2009).

Cyanide content of cassava differs among varieties, and for the same variety increases with the increase of drought due to a water stress on the plant (Cardoso et al., 2005). Sundaresan and other (1987) have classified roots according to their bitterness: non-bitter roots usually have a cyanogenic glucoside concentration <100 mg HCN equivalents/kg fresh weight (FW), bitter roots range from 100 to 450 mg HCN equivalents/kg FW, and very bitter roots have a concentration >450 mg HCN equivalents/kg FW. Cyanide content also varies among plants of the same cassava variety and within the roots of the same plants (Cooke et al., 1978). Indeed, cyanide content can vary along the length of the root (Cooke et al., 1978; Bradbury et al., 1991; Bokanga and Otoo, 1991; Bokanga, 1994) and a radial gradient also exists (Cooke, 1978; Heuberger, 2005); the apical root tip has cyanide content 60% higher than the basal root tip (Bradbury et al., 1991; Heuberger, 2005). Similarly, Heuberger (2005) observed that the cyanide content in the center of cassava roots (37 mg/kg FW) was smaller than the one in the peripheral part of root parenchyma (135 mg/kg FW) and of root cortex (282 mg/kg FW).

A great number of recent studies reported about many biotechnological approaches to improve the safety and quality of cassava products (Santana et al., 2002; Shittu et al., 2007; Onitilo et al., 2007); the effect of different processing modalities of the roots on the level of toxic substances and functional properties has been also assessed (Cooke and Maduagwu, 1978; Nambisan and Sundaresan, 1985; Udensi et al., 2005). Boiling, steaming, baking and frying, drying, fermentation, steam distillation, starch production, as well as combination of more than one of thse methods have been implemented in order to reduce the cyanide levels.

Methods involving grating and crushing (tissue disintegration) are usually very efficient in cyanide removal because they completely break plant cells of cassava and allow direct contact between the enzyme linamarase (also called beta-D-glucosidase and found in the cell wall) and linamarin, resulting in the conversion into HCN, which either dissolve in water or is released into air (Oke, 1994; Cardoso et al.2005). Sun-drying and heap fermentation, on the other hand, are less efficient because peeled roots are usually cut in half longitudinally (Cardoso et al., 2005) and most of the plant cells remain intact; the hydrolysis of cyanogenic glucosides is prevented or reduced because linamarin and linamarase are located in different compartments of the plant cell. Heap fermentation retains half the cyanide of sundrying because of the presence of microflora that can break down the linamarin during the fermentation process (Padmaja et al., 1993; Essers, 1994). Boiling in water is relatively inefficient in cyanide removing (50%) mainly because linamarase is inactivated at the boiling temperature (100°C); however, it is still much more efficient than baking, steaming, or frying (15 to 20% of cyanogen removal). Dewatering after fermentation and/or grating seems to be the most efficient treatment in cyanides removal (70–95%) since either free or residual cyanides can be reduced (Hahan, 1988).

Although efficient processing techniques to remove cyanide have been developed, some derived foodstuffs still have final cyanide content quite above the FAO/WHO's safe recommendation (1991) of 10 ppm. Adindu and others (2003) reported that cassava flour, *fufu, gari*, and tapioca from Nigerian markets contained cyanide up to 30 ppm, which is well above the safe value. In East Africa, values that are even higher have been observed (Cardoso et al., 2005); indeed, Mlingi and Bainbridge (1994) reported values of cyanide concentrations in *makiopa* and *chinyanya* (sun-dried flours) to be above 130 ppm in Tanzania. The values vary by geographic location and are usually related to the amount of cyanide present in the raw product.

Besides cyanides, other important safety concerns are pesticides, heavy metals, and the contamination of the processed and stored cassava products by bacteria, yeast, and fungi, including toxigenic species.

2.3 Pesticides

Regarding pesticides, their use in cassava production strongly depends on the extent of the plantation. At the householder level, the use of pesticides is minimal due to the prohibitive costs and the long crop cycle, which may requires several applications. Considering larger cassava plantations, held by SME and LE—Small, Medium, and Large Enterprises, there is a greater tendency to pesticides application; this, per contra, results in a higher yield than at the householder level (Hillocks et al., 2002). Pesticides such as dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexanes (HCHs), aldrin, dieldrin, heptachlor, chlordane, and related compounds play an important role as environmental contaminants; they are all included in a broad range of organic micropollutants that have big ecological impact, a wide range of both acute and chronic health effects, including cancer, neurological damage, and birth defects (Marco and Kishimba, 2006).

Over the years, quality of pesticides has been improved, as they become more specific toward pests and generally less toxic to humans; despite this, still hardly any pesticide is harmless. The lack of knowledge and training on the side of the farmer leads to health hazards but also contributes to misuse and inefficient application of pesticides. The main problems are the inability to distinguish one pest from the other, the use of the wrong type of equipment and the combination of pesticides that should not be mixed. Given the nature of pesticides, the hazard could never be eradicated; the situation, however, could be improved with appropriate measures. Using better and properly functioning application of equipment and training farmers properly, for instance, could be means to partially solve the problems. Appropriate legislation and its actual implementation would also minimize the damages.

In some territories of Africa (Tanzania) has been reported a concentration of pesticides in cassava roots of 200–600 mg/kg, much above the maximum residual levels (MRLs) of 0.1–2 mg/kg (depending on a specific compound) fixed by the European Commission (2005). It must be highlighted that there is considerable potential for the use of biopesticides to replace the chemical ones in cassava pest management; the effectiveness of the hornworm bacolovirus and its successful implementation, especially in large plantation, exemplifies these possible trends (Hillocks et al., 2002).

2.4 Heavy Metals

Among other routes, food is one of the main sources of consumer exposure to heavy metals. Since increased dietary metals intake may contribute to the development of various disorders, there is a necessity for monitoring of these substances in the human diet. Heavy metals show a significant build-up with contamination; long-term accumulation of heavy metals in soils, water, and air has led to contamination of food crops. Cassava and cassava-derived products may have harmful level of heavy metals like cadmium, chromium, nickel, lead, manganese, zinc, mercury, and iron (Idodo-Umeh and Ogbeibu, 2010; Emmanuel et al., 2013). One of the main reasons for cassava heavy metal contamination is that one the most common methods of drying the crop is along the highways, especially in the Northern part of Nigeria. Here, food crops such as cassava, maize corns, millets, guinea corns, and a varieties of vegetables are produced in large quantities; in these cases concentration of cadmium (Cd) and lead (Pb) has been reported to be higher than the safe limits of 0.10–

0.20 mg/kg fixed by the European Commission (2006) for foodstuff of similar composition as cassava (like bran, germ, wheat, rice, and vegetables).

2.5 *Mycotoxins*

Post-harvest spoilage by filamentous mold is one of the most important threats associated with processed and stored food products worldwide. Discoloration, quality deterioration, reduction in commercial value, and production of mycotoxins, which are secondary metabolites, have been linked to moldy contaminated foods (Gnonlonfin et al., 2012). The warm and humid climates that prevail in Tropical Africa provide favorable conditions for the spread and subsequent establishment of these organisms in numerous foodstuffs. The aflatoxins producer molds, namely, *Aspergillus flavus* Link, *Aspergillus parasiticus* Speare, and *Aspergillus nomius* Kurtzmanare, are the most harmful, and are known for their toxicity, carcinogenicity, and mutagenicity in experimental animals (Essono et al., 2009). Aflatoxin synthesis in food commodities is induced by high levels of carbohydrates and low levels of proteins, since carbohydrates provide the two carbons precursors for the toxin synthesis. Therefore, aflatoxins may also be a problem in all that products with comparable composition of cassava, such as yam (*Dioscorea* spp.). Aflatoxin formation and final content depends on several parameters including pH, moisture, storage duration, types of foodstuffs, level of initial contamination by the aflatoxin-producing fungi, processing practices, and storage facilities (Odoemelam and Osu, 2009). Very few studies on aflatoxins content in cassava are available. A stepwise analysis reported by Essono and others (2009) indicated that aflatoxins levels were significantly correlated with processing practices, storage facilities, and storage duration of the cassava-derived product. The authors also reported a level of ca. 11 μg/kg in Nigerian cassava-derived products stored for eight weeks at an SME level. Manjula and other (2009) reported levels of aflatoxin B1 (which is the most toxic) varying from 0.3 to 4.4 μg/kg in cassava chips and flour, and from 0.1 to 13 μg/kg in stored cassava samples, in Tanzania and Republic of Congo.

The African standard (ARSO, 2012a) on the specification of cassava wheat composite flour fixed a limit of 10 μg/kg for aflatoxin of which not more than 5 μg/kg may be aflatoxin B1. A limit for aflatoxin content in cassava has not yet fixed by the European legislation; for products with similar composition, such as cereals and maize, which are subjected to sorting or physical treatments before human consumption, a limit of 4 and 10 μg/kg, respectively, has been established (EC no 1881/2006).

Further to aflatoxin, the presence of bacteria, both pathogenic and not, was also detected in cassava-derived products. Total mesophilic aerobic bacteria in cassava fermented product sold in some countries of Africa (such as Nigeria and Ghana) was found within the acceptable limits of $< 5 \log_{10}$ CFU/g while *Enterobacteriacea* were above the limit of $< 3 \log_{10}$ CFU/g; the presence of *Staphylococcus aureus*, which was detected above the maximum limit 2 $\log_{10}$ CFU/g, is suggestive of contamination from skin, mouth, and nose of the food handler indicating poor personal hygiene (Omafuvbe et al., 2007; ARSO, 2012a; Adebayo-Oyetoro et al., 2013; Kouamé et al., 2013).

2.6 *Improving Food Safety and Food Security through Processing Cassava into Different Foodstuffs*

The post-harvest storage/preservation and processing of cassava are hindered by its highly perishable nature, content of toxic compounds, ease of microbial contamination, and risk of sprouting due to increased metabolic activity (Gnonlonfin et al., 2012). Prior to harvest in fact, the roots of cassava can be kept in the ground up to two years but once harvested begin to deteriorate due to the high water content (60–65%). Therefore, over the years, cassava has been transformed into a number of products both for human consumption (depending on local customs and preference) and animal feeding. Industrial applications (biofuels, paper, textiles, plywood, and adhesives) are also gradually developing (Ukwuru and Egbonu, 2013). Currently, cassava roots are processed into several dry products with improved safety (since cyanide are almost totally reduced), with improved stability and durability, and with less volume, which also makes easier and less expensive the transport of cassava from rural areas (IITA, 1990; Ugwu, 1996). Traditional cassava processing methods for human food involves several steps, which include peeling, soaking, grinding, steeping in water, fermentation, drying, milling, roasting, steaming, pounding, and mixing in cold or hot water. Specific combination of these steps leads to a myriad of different cassava products with acceptable taste in a wide range of consumers (Bokanga and Otoo, 1991; Falade and Akingbala, 2010).

Among all derived products, the most important are the high-quality cassava flour (HQCF) from unfermented cassava, and *gari*, granular flour from fermented cassava (Oduro et al., 2000; Ukwuru and Egbonu, 2013). The most promising market is that of HQCF, for the replacement of wheat flour in the bakery sector (which would be also particularly useful for population affected by celiac disease) (Ohimain, 2014) and also as an alternative or component in traditional cassava product such as instant *fufu* in Ghana and fermented *fufu* in Nigeria (Adebayo et al., 2010). The main reasons for focusing on HQCF are that higher value can be added at the rural household level by processing the intermediate product (cassava grits or waste paste), thereby increasing income for farmers; the requirement for the capital investment is lower, and less environmental damage is caused than in starch manufacture. Moreover, many farmers already know how to obtain the basic raw materials for HQCF (grated cassava). Consequently, HQCF offers the easiest entry point, in the short term it would benefit the most small holder farmer/processor and it would provide a spring board for investment in other product (Ukwuru and Egbonu, 2013; Ohimain, 2014). The method of flour preparation is important in determining the quality of the final product, mainly for bread preparation (Ohimain, 2014); the process flow is reported in Fig. 1. All the steps for the production of flour from cassava used to be carried out manually. This practice has led to the production of poor quality flours having defects such as yellow coloration, high microbial loads, and odor problems. Manual methods are often slow, producing flour that is fermented or partially fermented, which is unsuitable for bread production. HQCF has to be produced rapidly to prevent fermentation. Cassava peeling is the most tedious and time-consuming operation since it is done manually, mostly by women. Manual peeling also increases contamination because of human contact with the product. Although mechanical peelers have been developed and tested, their use is still not widespread (Ohimain, 2014), mostly because of high proportion of wastages. Hence, hand peeling is currently the only feasible option (Kolawole et al., 2012). Equipments such as mechanical graters, hydraulics jacks, motorized sieves, and flash dryers have been adopted to speed up HQCF production and to improve the quality (Sanni et al., 2006). Time for dewatering is very critical and it should be as little as possible.

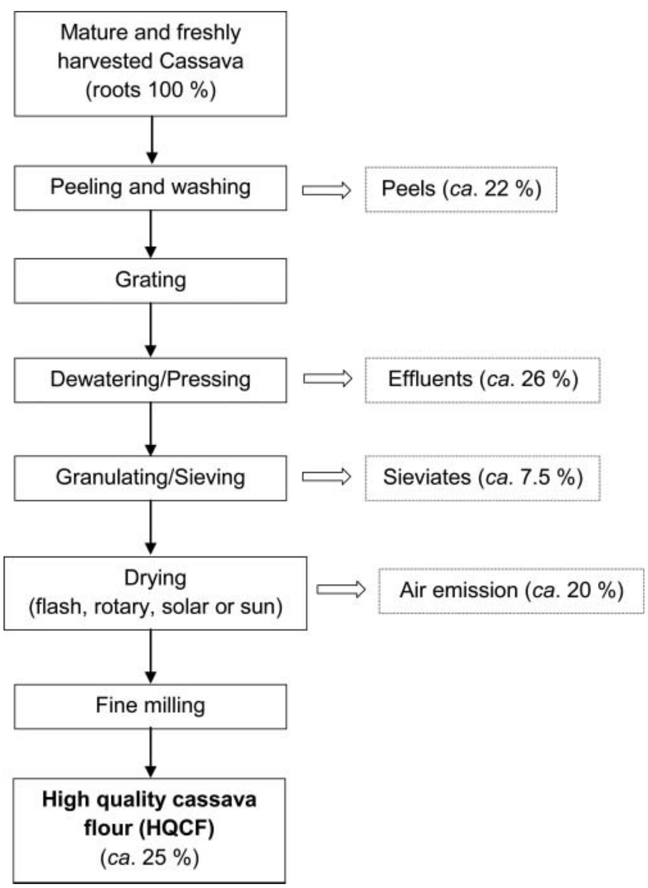

Figure 1 Process flow of high quality cassava flour (HQCF) from cassava roots in West Africa (IITA, 2005a; Ohimain, 2014).

Kolawole et al. (2012) reported that improved dewatering system with a mechanical press can successfully dewater grated cassava mash with –two to four hours. Cassava flour produced under rapid dewatering systems precluding fermentation mostly produces flour with low pH, which is one of the challenges faced by small processors. The low pH, i.e., acidity, is due to the presence of high level of cyanide that would normally be removed during fermentation processes. The standard for HQCF is presented in Table 1. The strict requirement of pH values in the range 5–8 is a major challenge for small processors, mainly because pH determines the price of the product, where the higher the pH the higher the price (Ohimain, 2014).

Drying has been identified as the critical step for expanding the processing of cassava into HQCF. Various drying options have been considered so far by the International Institute of Tropical Agriculture (IITA, 2005). Local processors expose cassava mash on polythene sheet directly to the sun, where this is referred to as "sun drying." The IITA observed that drying at rural or domestic levels cannot be done artificially because of the high capital investment in equipment and energy required and hence, natural sun drying is performed. However, sun drying is beset by several inherent drawbacks, such as susceptibility to damage due to inclement weather, slow drying rates, contamination, theft or damage by birds, rats or insects. In the light of these limitations—the high cost and low utilization of more efficient traditional dryers—the adoption of a modified sun drying process, like flash, rotary, or solar drying, have been considered for HQCF production in rural areas (IITA, 2005; Sanni et al., 2009). However, the industrialized drying process is most energy consuming; in fact, after cost of cassava roots (accounting for 50% of the total), drying is the major cost elements (accounting for 12%) (Oludiran, 2012).

Gari (or *garri*) is a fermented partially gelatinized granular product of variable granule size, obtained by cassava fermentation, and is only produced in Africa. It is very common in Nigeria, Sierra Leone, and Ghana, where it is an export commodity since 1985. Also, in Ghana more than 70% of cassava is processed into *gari*. The popularity of *gari* is due to its cheapness, longer shelf-life, lower bulk (compared to other cassava products), and ease of preparation for consumption (Oduro et al., 2000). Five key operations are required: peeling, grating, fermentation and pressing, sieving, frying, and drying (IITA, 2005a) (Fig. 2). These operations are traditionally carried out entirely by women, usually starting very early in the morning harvesting, peeling, and washing the roots in the field, then carrying the cleaned roots to the village where the rest of the operations are carried out (Diop, 1998). Currently, major drawback is the production of high-quality *gari* (Table 2). The commodity is obtained at household level with different methodologies depending on the area; the traditional process makes difficult the quality control, takes a long time, and has a quite low yield, 22–34% of the starting tuber (Oduro et al., 2000; Ohimain, 2014).

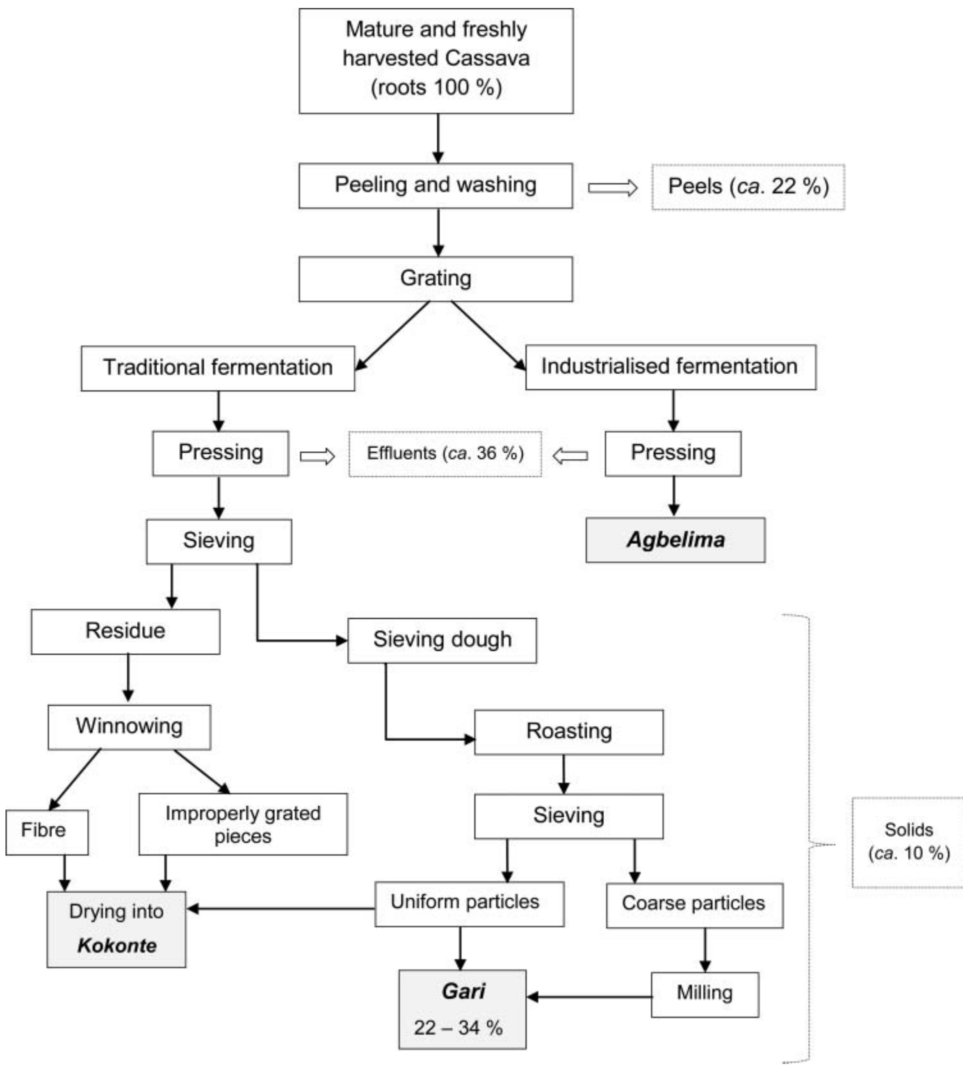

Figure 2 Process flow for *gari, kokonte*, and *agbelima* in West Africa (Oduro et al., 2000; IITA, 2005a).

Environmental impact of HQCF and *gari* is significant, and currently scarcely documented. Most cassava processing wastes are not treated, but are freely disposed into the environment causing pollution and odor problems. Household animals such as goats and sheep, and also fish, have been killed by cyanide from cassava effluents (Ohimain, 2014). Moreover, Owuamanam (2007) reported that the production of unfermented cassava flour for bread making may not address the issue of reduction of cyanide in HQCF. Also the use of fuels like HPFO (high pour fuel oil) and waste engine oil to operate flash dryers have led to air quality impacts releasing smokes, particulates, metals, and hydro carbons into the atmosphere.

Besides HQCF, other main cassava-derived commodities produced at the industrial level are starch, tapioca (in Africa, Asia, and South-America), and glucose syrup (Asia); among traditional products apart *gari*, there are *agbelima* (fermented cassava dough) and *kokonte* (dried cassava pieces) (Fig. 2) produced in Ghana (Falade and Akingbala, 2010), *lafun* (fine cooked fermented cassava flour), *fufu* (a wet paste of boiled cassava starch), and *fufu* flour (a dry paste of cassava starch) produced in Nigeria (Omafuvbe et al., 2007), wet starch (produced in Asia) and cassava chips produced either in Africa or Asia (Gnonlonfin et al., 2012).

3. YAM

3.1 Nutritional Value

The global distribution of yam species varies greatly from African to Asian regions in genotype, wild and cultivated specie. Generally, yam provides energy in an amount ranging between 80 and 120 Kcal/100 g (Oke, 1990; Polycarp et al., 2012). Depending on the variety, moisture content of fresh tubers ranges between 58 and 80%, ash between 0.5 and 1.2%, carbohydrates between 17.5 and 28%, crude proteins between 1.5 and 6%, fat between 0.1 and 0.2%, and fiber between 0.6

Table 2 Physico-chemical and microbiological specification for high-quality cassava flour (Codex Alimentarius, 1985; Falade and Akingbala, 2010; ARSO, 2012b; Ohimain, 2014) and for *gari* (Codex Alimentarius, 1985; Oduro et al., 2000; ARSO, 2012c)

Parameter	HQCF	*Gari*
pH	5.0–8.0	3.5–4.5
Total acidity, % by mass, maximum	0.25	0.6–1 (% lactic acid)
Moisture content, % by mass, maximum	12	7–12
Ash, % by mass, maximum	0.9	1.5
Cyanide, mg/kg, maximum	10	20
Starch content, % by mass, minimum	60	–
Crude fiber, % by mass, maximum	0.2 (dry basis)	2
Sodium chloride, % dry weight, maximum	–	2
Total aflatoxinas and aflatoxin B1, μg/kg	10 and 5	10 and 5
Color	white	white
Odor	none	none
Taste	none or sweet	slightly sour and sharp
Particle size	0.250 mm	0.350 mm (extra fine) 1–0.350 mm (fine) 1.4–1 mm (coarse) >1.4 mm (extra coarse) Unclassified *gari*
Total plate count, CFU/g	10^5	10^3
Vibrio cholera, CFU/g	absent	–
Escherichia coli, CFU/g, maximum	absent	absent
Bacillus cereus, 25 g, maximum	–	absent
Salmonella, 25 g, maximum	absent	absent
Yeast and mold, CFU/g, maximum	10^3	10^3
Staphylococcus aureus, CFU/g, maximum	10^2	10^2
Coliforms, g/100 g	absent	absent
Heavy metals	Not yet defined for these commodities*	

Note: (*) the products should comply with the limits reported in the *Codex Alimentarius* standard for contamination of food and feed (2005).

and 1.5%, on fresh basis (Table 1). Among all varieties, *Dioscorea rotundata* has the lowest moisture content, which makes it suitable for the production of high yield flour (Polycarp et al., 2012). Like other crops, yam is not a good source of essential amino acids; it is rich in aspartic and glutamic acids, in the essential amino acids phenylalanine and threonine but limited in the sulfur amino acids such as cysteine, methionine, and tryptophan (Bhandari et al., 2003). The most nutritious variety was reported to be the *Dioscorea dumetorum* (yellow yam) that has fairly high protein content and well-balanced amino acids (Polycarp et al., 2012). On the contrary, due to the protein deficiency, the white yam (*Dioscorea rotundata*) consuming areas of Africa have a high incidence of *kwashiorkor*, a serious medical condition in children caused by proteins deficiency (Gladstone et al., 2014). Therefore, a yam-driven diet should be supplied with more protein-rich foods in order to support active and healthy growth in infants. Except for potassium, vitamin B_6, and vitamin C, yam is a food with moderate nutrient density. It has good levels of potassium, manganese, thiamin, and dietary fiber, while being low in saturated fat and sodium. The tuber generally has a lower glycemic index, about 54% of glucose per 150 g serving, compared to potato products (Oke, 1990). Yam tubers (but also yam roots) have been used since the pre-history not only as a food but also as traditional medicine since it contains some essential dietary nutrients. Numerous studies have shown that yams are sources of diverse nutrients and non-nutrient molecules, many of which display bioactive properties. Some examples of such non-nutrient bioactive molecules in yam are polyphenols and organic acids. The tuber contents ca. 170 mg/100 g of total polyphenols and ca. 1850 mg/100 g on fresh weight of organic acids, namely, oxalic, malic, citric, and succinic, in order of relevance (Bhandari and Kawabata, 2004). The African yam (*Dioscorea* spp.) contains thiocyanate that was suggested as potentially protective against sickle cell anemia (SCA), and the rarer incidence of this illness in Africans population than in the African-American one could be explained with the higher thiocyanate intake through yam consumption (Chandler and Day, 2012).

Unlike cassava, most varieties of edible, mature, cultivated yam do not contain toxic compounds; again, there are exceptions for some cultivars that contain the toxic molecule discorene (Opara, 2003). Currently, serious problems for the storage and the consumption on yam are enfaced, as reported in the following sections.

3.2 Storage

Roots as cassava and tubers such as yam are living organisms and, therefore, they continue to breath during storage. The respiration process results in the oxidation of the starch (a polymer of glucose) contained in the cells of the tuber, which gets converted it into water, carbon dioxide, and heat energy. During the starch transformation, the dry matter of the tuber is reduced. Among the major roots and tubers, properly stored yam is considered to be the most perishable (Opara, 2003). Successful storage of yams requires initial selection of sound and healthy yams, proper curing, if possible combined with fungicide treatment; adequate ventilation to remove the heat generated by respiration of the tubers; regular inspection during storage and removal of rotting tubers and any sprouts that develop, and protection from direct sunlight and rain (Oke, 1990). Storing yam at low temperature reduces the respiration rates; however, it has been noticed that temperatures below 12°C can also cause damage through chilling; this can lead to a breakdown of internal tissues, increasing water loss, and yam's susceptibility to decay. The symptoms of chilling injury are not always obvious when the tubers are still in cold storage; the injury becomes noticeable as soon as the tubers are restored to ambient temperatures. The best temperature to store yams seems to be between 14 and 16°C with controlled climatic conditions and humidity at 70–80% (relative) after a process of curing (Chou et al., 2006). However, currently, most countries that grow yam as food staple are too poor to afford high technology storage systems. Storage losses for yams are very high in Africa, with insects alone causing over 25% harvest loss within four months (Opara, 2003).

3.3 Pesticides

Pesticides residues in yam are also a safety concern. Up the last two decades, level of the substance lindane (banned in 2009 by the Stockholm Convention) higher than the MRLs fixed by EU (0.01 mg/kg) has been found in yam flour (Codex Alimentarius Commission, 1994), while there is a lack of more recently data on pesticides content in yam. Accurate data on actual pesticide used in developing countries and trends in use at national level or for major cropping systems are rarely available, and data may not include foreign government donations, an important source of pesticides into African agriculture (Williamson et al., 2008). Nevertheless, average pesticide used per hectare in Africa is low, reported as 1.23 kg/ha, compared with 7.2 and 3.1 kg for Latin America and Asia, respectively.

As mentioned for cassava, highly inefficient practices include the usage of inappropriate products, incorrect dosage, timing and targeting of application, non-calibrated, and poorly maintained or leaking equipment. Inappropriate use has consequences not only for the effectiveness of the intended pest control but also for operator and consumer health, farm livestock, soil organisms, wildlife and vegetation, and contamination of soil, water, and air (Kishi, 2005; Pretty and Hine, 2005). Extremely hazardous practices include the use of unauthorized or banned products, cocktail mixes of products, mixing with bare hands, splashing pesticides onto crops using brushes or twigs, lack of minimal protective clothing and even tongue-testing to assess concentration strength (Sibanda et al., 2000; Tettey, 2001; Addo et al., 2002; Dinham, 2003).

3.4 Heavy Metals

Recently, the consumption of yam-derived foodstuffs is increasing and the precise assessment for the potential metal contamination of final yam products, as well as during the food manufacturing, is required (Shin et al., 2013). Level of heavy metals is different depending on the growing area. In some parts of Africa (South Eastern Nigeria) Cd concentration in yam has been reported to be 0.11 mg/kg into the limit established by the EU and WHO (0.10–0.20 mg/kg), while Pb was not detectable and Ni seems to be lower than the maximum natural content found in most food of 0.5 mg/kg (IARC, 1990). On the other hand, Wilberforce and Nwabue (2013) reported values of 0.21 mg/kg for Pb, 42 mg/kg for Cu, 24 mg/kg for Zn, 18 mg/kg for Mn, and 12 mg/kg for Ni, again in South Eastern Nigeria, in the Ebonyi State.

In Asia (specifically South-Korea), Cd concentration (ca. 0.045 mg/kg fresh weight) was found quite below the safety levels established by EU, as well as Cr, As, Se, and Hg; on the contrary Pb concentration (0.2–0.7 mg/kg) was found higher than the limits (Shin et al., 2013). Therefore, concentration of heavy metal in yam foodstuffs varies significantly, depending on the cultivation area and on the type of processing.

3.5 Mycotoxins

Yam contamination by aflatoxygenic molds is unfortunately very common, it is the main cause of rots and it is mainly due to the high moisture content. As mentioned for cassava, these molds may reduce nutrient contents of the food and produce mycotoxins that could cause serious health hazard to humans and animals (Peraica et al., 1999; Adebayo-Tayo et al., 2006; Djeri et al., 2010).

For yam and yam-derived products, the contamination with aflatoxigenic molds has received great deal of attention, as for cassava, because the frequent incidence of these toxins in agricultural commodities has a potential negative impact. Contamination mainly occurs because harvest and post-harvest techniques inadequate for the prevention of mold growth are seldom practiced, where inadequate storage facilities make the problem worse (Jonathan and Olowolafe, 2001; Adebayo-Tayo et al., 2006). Pathogenic molds detected in yam were *Aspergillus flavus, Aspergillus niger, Botryodiplodia theobromae, Fusarium oxysporum, Fusarium solani, Penicillium chrysogenum, Rhizoctonia spp., Penicillium oxalicum, Trichoderma viride*, and *Rhizopus nodosus* (Okigbo and Ikediugwu, 2002; Aidoo, 2007). Yam flour may be particularly contaminated by species of the species *Aspergillus, Mucur, Rhizopus*, and *Penicillium* that add the genera *Fusarium* in the case of yam chips. Among 18 different types of aflatoxins that have been identified, major ones are aflatoxin B1, B2, G1, and G2, where aflatoxin B1 (AFB1) exists predominantly in food products and is the most toxic, it is a potential genotoxic carcinogen in laboratory animal and it is a liver carcinogen in human (Somorin et al., 2012). Occurrence of aflatoxin B1 has been identified in some food commodities such as dry yam chips, cassava flour, *gari*, maize flour, etc., sold in African markets, with its concentration sometimes above the tolerance level of 15 μg/kg total aflatoxin fixed by the Codex Alimentarius Commission (Gbolagade et al., 2011; Somorin et al., 2012). For instance, concentrations of 14 μg/kg AFB1 and 17 μg/kg AFG1 were reported in yam chips in South-West Nigeria, while 30–186 μg/kg for AFB1 were reported for yam chips in Benin (Jimoh and Kolapo, 2008).

3.6 Improving Food Safety and Food Security of Yam through Processing into Different Foodstuffs

Yams are mainly grown for direct human consumption. Growth of the tuber is seasonal, on the contrary of cassava, which is perennial. Like other tubers, it is grown in the rainy season and harvested toward the end, which arise the problem of abundance just after harvest and scarcity a few months after, due to poor storage systems among farmers (Opara, 2003). Storage of yam poses a serious concern; the difficulty in storage raises the problems of farmers benefiting from the incidence of seasonal price increase (Akangbe et al., 2012). In Nigeria, yam has become expensive and relatively unaffordable in urban areas as production has not kept the pace with population growth; this led to demand exceeding supply. Also, because of the poor storability, farmers sell the product just after harvest to avoid losses, and this result in low income or reduced profits. Therefore, there are several constraints to the yam industry in Africa (Kleih et al., 2012).

This problem prompted the producers, especially in Nigeria, to process yam into various stable, intermediate end products as an alternative means of reducing the high post-harvest losses (Aderiye and Ogunjobi, 1998) . Yam flour, chips, pellets, and starch are currently produced either by traditional (household) or industrial methods (small-medium enterprises). The yam tubers are partially peeled, sliced into pieces, and parboiled. They are left inside water (used for parboiling) to undergo natural fermentation for an overnight to four to five days; then, they are dried into chips (called *gbodo* when sun dried in Nigeria), that can be further milled into flour (known as *elubo* in Nigeria) (Ojokoh and Gabriel, 2010; UNESCO, 2010). Process flow for yam flour and chips is reported in Fig. 3. There is not yet a specification standard for the yam-derived products, however all of them should comply at least with the specification reported for yam (Codex Alimentarius, 2005; ARSO, 2012d). Flour can be reconstituted with hot water to form paste or dough known as *amala* and *kokonte* among people of Nigeria and Ghana, respectively. The reconstituted flour is a popular food in Nigeria (Akissoe et al., 2003, Abulude and Ojediran, 2006). Yam flour could be fortified with other flours such as plantain, soya, and wheat, in order to improve its nutritional value (Abulude and Ojediran, 2006). In has been observed that there is a gap in the supply of instant yam flour; the growing of the middle class in developing countries is resulting in a crescent need for hygienically well packaged and ready-to-use products that are still unavailable in many areas of African countries (Foraminifera Market Research, 2012).

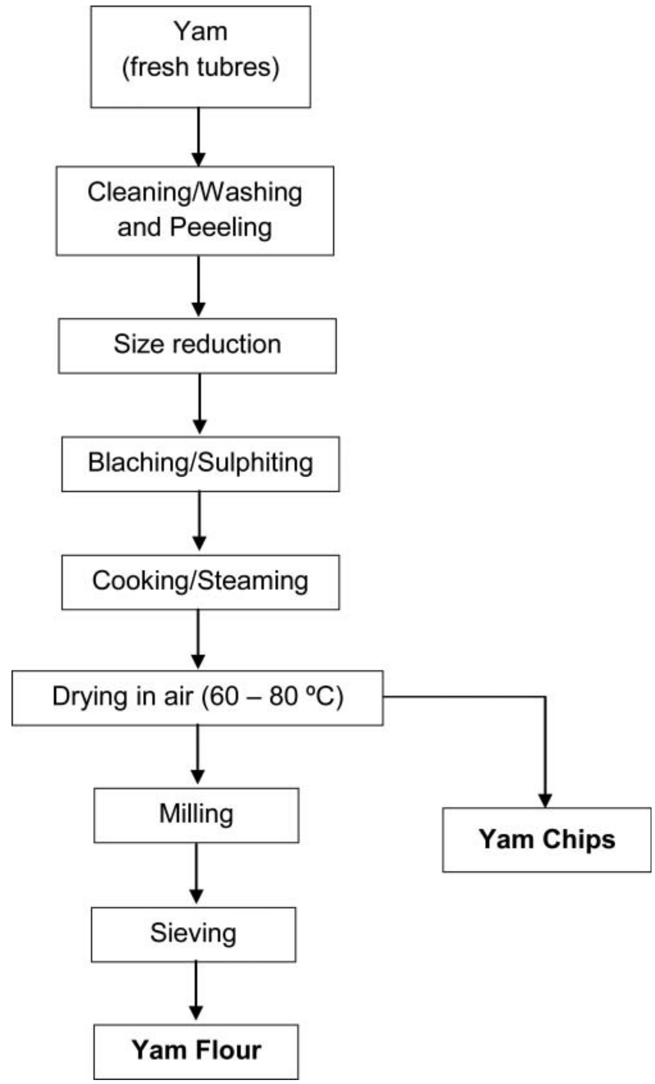

Figure 3 Industrial process flow for yam flour and yam chips (Ojokoh and Gabriel, 2010; UNESCO, 2010).

4. CONCLUSIONS

Cassava cultivation underwent many agricultural improvements in the last 20 years. In the decade of the nineties, the cassava production in many African countries increased through the adoption of disease and pest resistant varieties, besides the application of improved processing technology that reduced processing time and encouraged further production (Adeniji et al., 2001). Regarding yam, it is imperative to examine and improve the storage strategy practiced by farmers. Post-harvest losses of yam and other crops are one of the important sources of food insecurity in Africa. According to AMCOST (2006), pre- and postharvest food crop loss among African countries is estimated at about 10%, which is higher than the global average. Even though peelings and waste from yam are often used for feeding poultry and livestock, losses associated with the crop limit the potential income of the farmers, threaten food security and exacerbate conditions of poverty among rural households, whose income stream depends on the ability to store excess farm produce for a later date (Thamaga-Chitja et al., 2004).

One of the greatest challenges of food processing in the developing countries is the transformation of traditional or indigenous processing method into modern industrial operations. Indigenous processing techniques for making traditional food product differ within and between countries because of differences in food culture, available raw materials, and processing equipment utilized (Falade and Akingbala, 2010). Many traditional methods of food processing and preservation require review and upgrading for industrial production, in order to improve food safety and security for cassava and yam crop and derived foodstuffs.

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