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Review

Cassava post-harvest processing and storage in Nigeria: A review

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Cassava is an important root crop consumed as a staple food, boiled, baked or often fermented into other foods and beverages all over the world. It is a very good vehicle for addressing some health related problems and also serve as security food. Cassava undergoes postharvest physiological deterioration (PPD) once the tubers are separated from the main plant. PPD is one of the main obstacles currently preventing farmers from exporting fresh cassava abroad thereby generating income from foreign exchange. Cassava can be preserved in various ways such as coating with wax and freezing. Recent development in plant breeding has resulted in cassava that is tolerant to PPD. Genetic manipulation was considered most appropriate to solving the PPD challenge by adding new traits to elite genotypes without altering other desired characteristics. Processing cassava affects the nutritional value of cassava roots through modification and losses in nutrients of high value. The processing methods include peeling, boiling, steaming, slicing, grating, soaking or seeping, fermenting, pounding, roasting, pressing, drying, and milling. The products from cassava are: High Quality Cassava Flour (HQCF), cassava chips, garri, starch, ethanol etc.

Key words: Post-harvest, storage, processing, cassava, high quality cassava flour (hqcf).

INTRODUCTION

Cassava is a major staple crop in Nigeria, as cassava and its product are found in the daily meals of Nigerians. Currently, cassava is undergoing a transition from a mere subsistent crop found on the field of peasants to a commercial crop grown in plantations. This unprecedented expansion on this crop is attributed to its discovery as a cheap source of edible carbohydrate that could be processed into different forms of human delicacies and animal feeds. Cassava is drought-tolerant, staple food crop grown in tropics and subtropical areas. Cassava is to African peasant farmers what rice is to Asian farmers or wheat and potatoes are to European farmers (El-Sharkawy, 2003).

Cassava (*Manihot esculenta* Crantz) is a perennial woody shrub with an edible root, which grows in tropical and subtropical areas of the world Cassava plays a particularly important role in agriculture in developing countries, especially in sub-Saharan Africa, because it does well on poor soils and with low rainfall, and because it is a perennial crop that can be harvested as required.

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Its wide harvesting window allows it to act as a famine reserve and invaluable in managing labour schedules. It offers flexibility to resource-poor farmers because it serves as either subsistence or a cash crop (Stone, 2002).

Furthermore, cassava is the source of raw materials for a number of industrial products such as starch, flour and ethanol. The production of cassava is relatively easy as it is tolerant to the biotic and edaphic encumbrances that hamper the production of other crops. 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 staple food crops. Once out of the ground, some root crops have a shelf life of only few days. Roots as living organs of plants continue to metabolize and respire after harvest. Cassava has a shelf life that is generally accepted to be of the order of 24 to 48 h after harvest (Andrew, 2002). Cassava utilization patterns vary considerably in different parts of the world. In Nigeria, the majority of cassava produced (90%) is used for human food (IITA, 2010). Cassava is very versatile and its derivatives and starch are applicable in many types of products such as foods, confectionery, sweeteners, glues, plywood, textiles, paper, biodegradable products, monosodium glutamate, and drugs. Cassava chips and pellets are used in animal feed and alcohol production. Animal feed and starch production are only minor uses of the crop in Nigeria. Cassava, in its processed form, is a reliable and convenient source of food for tens of millions of rural and urban dwellers in Nigeria (IITA, 2010). The aim of this study is to review the post harvest processing and storage of cassava in Nigeria, in order to improve on the processing and storage equipment for cassava.

Global situation of cassava

Nigeria currently produces about 54 million metric tonnes (MT) per annum (FAO, 2013), making her the highest cassava producer in the world, producing a third more than Brazil and almost double the production capacity of Thailand and Indonesia. However, Nigeria is not an active participant in cassava trade in the international markets because most of her cassava is targeted at the domestic food market. The production methods are primarily subsistence in nature and therefore unable to support industrial level demands (FAO, 2013). More than 248 million tons of cassava was produced worldwide in 2012 of which Africa accounted for 58% (IITA, 2012). In Ghana, Cassava accounts for a daily caloric intake of 30% and is grown by nearly every farming family. The importance of cassava to many Africans is epitomised in the *ewe* (a language spoken in Ghana, Togo and Benin) name for the plant, *agbeli*, meaning "there is life" (IITA, 2010). Cassava leaves are important in some countries, for instant; in Democratic Republic of Congo cassava leaves have greater market value than roots.

In the subtropical region of southern China, cassava is the fifth-largest crop in term of production, after rice, sweet potato, sugar cane and maize. China is also the largest export market for cassava produced in Vietnam and Thailand. Over 60% of cassava production in China is concentrated in a single province, Guangxi, averaging over 7 million tons annually (Frederick, 2008). The world trade in pellets have long been dominated by Thailand, beginning around 1967, a few years after the start of its cassava exports to the European Union (EU). Although Thailand exports cassava chips and pellets to other Asian countries, especially China, where pellets are used both for animal feed and for the production of ethanol, the production and trade in cassava starch has significantly increased in recent years. Cassava starch has product characteristics that are technically superior to those of corn (maize) starch and this sub-sector promises to be a viable new market segment for industrial cassava. Already, in order to meet the global starch demand, large companies specializing in the production of starch and modified starch have invested hugely in Thailand, Brazil and Indonesia. Cassava flour is widely consumed in Brazil and in most of Latin America, as *farinha (farinha is important just in Brazil)*, with various levels of sophistication in its processing from primitive family to large mechanized methods in factories.

THE NIGERIAN CASSAVA INDUSTRY

Over time, cassava has evolved from being a peasant's crop to cash and industrial crop. Cassava in Nigeria is used for two main purposes: 90% as human food and only 5 to 10% as secondary industrial material (used mostly as animal feed). About 10% of Nigeria's industrial demand consists of high quality cassava flour (HQCF) used in biscuits and confectioneries, dextrin pregelled starch for adhesives, starch and hydrolysates for pharmaceuticals products and seasonings, Seventy percent (70%) of cassava processed as human food is *gari* (Cassava Master Plan, 2006). Other common cassava products for human foods are *lafun* and *fufu/Akpu.* Processed products can be classified into primary and secondary products. The former, e.g. *gari*, *fufu*, starch, chips, pellets are primary products which are obtained directly from raw cassava roots, while the latter are obtained from further processing of primary products (e.g. glucose syrup, dextrin, and adhesive are obtained from starch).

Cassava production in Nigeria is increasing every year but Nigeria continues to import starch, flour, sweeteners that can be made from cassava (Cassava Master Plan, 2006). This paradox is due to how cassava is produced, marketed, and consumed in Nigeria, in a largely subsistence to semi-commercial manner. To fully exploit cassava's immense potential, especially as a replacement of imported raw materials and as an export commodity, there is a need to change how cassava is grown and traded in the country using a value-chain development approach. Nigerian cassava-based industrial products are just a fraction of imports, and the growth potential is huge (Cassava Master Plan, 2006).

Cassava transformation that builds upon two previous efforts has been embarked upon under the Agricultural Transformation Program of President Goodluck Jonathan and implementation by the Honourable Minister of Agriculture, Dr. Akinkumi Adesina. The cassava transformation seeks to create a new generation of cassava farmers, oriented towards commercial production and farming as a business, and to link them up to reliable demand, either from processors or a guaranteed minimum price scheme of the government. The overarching strategy of the cassava transformation is to turn the cassava sector in Nigeria into a major player in local and international starch, sweeteners, ethanol, HQCF, and dried Chips industries by adopting improved production and processing technologies, and organizing producers and processors into efficient value-added chains. There are three major limitations of increased utilization of cassava roots: poor shelf life, low protein content and their naturally occurring cyanogens (IITA, 2012).

Nutritional value of cassava roots

The nutritional composition of cassava depends on the specific tissue (root or leaf) and on several factors, such as geographic location, variety, age of the plant, and environmental conditions. The roots and leaves, which constitute 50 and 6% of the mature cassava plant, respectively, are the nutritionally valuable parts of cassava (Tewe and Lutaladio, 2004). The nutritional value of cassava roots is important because they are the main part of the plant consumed in developing countries.

Cassava root is an energy-dense food. In this regard, cassava shows very efficient carbohydrate production per hectare. It produces about 250,000 calories/hectare/day (Julie et al*.,* 2009), which ranks it before maize, rice, sorghum, and wheat. The root is a physiological energy reserve with high carbohydrate content, which ranges from 32 to 35% on a fresh weight (FW) basis, and from 80 to 90% on a dry matter (DM) basis (Julie et al., 2009). Eighty percent of the carbohydrates produced is starch (Gil and Buitrago, 2002); 83% is in the form of amyl pectin and 17% is amylose (Rawel and Kroll, 2003). Roots contain small quantities of sucrose, glucose, fructose, and maltose (Tewe and Lutaladio, 2004). Cassava has bitter and sweet varieties. In the latter varieties, up to 17% of the root is sucrose with small amounts of dextrose and fructose (Charles et al., 2005). Raw cassava root has more carbohydrate than potatoes and less carbohydrate than wheat, rice, yellow corn, and sorghum on a 100-g basis. The fibre content in cassava roots depends on the variety and the age of the root. Usually its content does not exceed 1.5% in fresh root and 4% in root flour (Gil and Buitrago, 2002). The lipid content in cassava roots ranges from 0.1 to 0.3% on a FW basis. This content is relatively low compared to maize and sorghum, but higher than potato and comparable to rice.

Cassava roots have calcium, iron, potassium, magnesium, copper, zinc, and manganese contents comparable to those of many legumes, with the exception of soybeans. The calcium content is relatively high compared to that of other staple crops and ranges between 15 and 35 mg/100 g edible portion. The vitamin C (ascorbic acid) content is also high and between 15 to 45 mg/100 g edible portions (Charles et al*.,* 2004). Cassava roots contain low amounts of the B vitamins, that is, thiamine, riboflavin, and niacin (Table 1), and part of these nutrients is lost during processing. Usually the mineral and vitamin contents are lower in cassava roots than in sorghum and maize (Gil and Buitrago, 2002). The protein, fat, fibre, and minerals are found in larger quantities in the root peel than in the peeled root. However, the carbohydrates, determined by the nitrogen-free extract, are more concentrated in the peeled root (central cylinder or pulp) (Gil and Buitrago, 2002). Thus, cassava roots are rich in calories but low in protein, fat, and some minerals and vitamins. Their nutritional value is, consequently, lower than those of cereals, legumes, and some other root and tuber crops such as potato and yam.

Processing effects on nutritional value

Processing cassava affects the nutritional value of cassava roots through modification and losses in nutrients of high value. Analysis of the nutrient retention for each cassava edible product (Table 2) shows that raw and boiled cassava root keep the majority of high-value nutrients except riboflavin and iron. *Gari* is a common root product that involves grating, fermenting, and roasting. *Gari* and products obtained after retting of cassava root with peel are less efficient than boiled root in keeping nutrients of high value but are better than products obtained after retting of cassava roots. However, the latter is richer in riboflavin than sun-dried flour. *Fufu,* an important staple in Africa, is a mashed cassava root product that is allowed to ferment with *Lactobacillus* bacteria (Sanni et al., 2002). *Medua-me mbong* is a root product that requires only boiling and prolonged washing. However, *medua-me-mbong* has the poorest nutritional value compared to other cassava products with the exception of calcium content (Julie et al., 2009). In contrast to boiled cassava, processed root loss a major part of dry matter, carbohydrates, protein,

Table 1. Proximate, vitamin, and mineral composition of cassava roots and leaves.

Proximate composition	Raw cassava (100 g)	Cassava roots	Cassava leaves
Food energy (kcal)	160	110 - 149	91
Food energy (KJ)	667	526 - 611	209 - 251
Moisture (g)	59.68	45.9 to 85.3	64.8 to 88.6
Dry weight (g)	40.32	29.8 to 39.3	19 to 28.3
Protein (g)	1.36	0.3 to 3.5	1.0 to 10.0
Lipid (g)	0.28	0.03 to 0.5	0.2 to 2.9
Carbohydrate, total (g)	38.06	25.3 to 35.7	7 to 18.3
Dietary fiber (g)	1.8	0.1 to 3.7	0.5 to 10.0
Ashe (g)	0.62	0.4 to 1.7	0.7 to 4.5
Vitamins			
Thiamin (mg)	0.087	0.03 to 0.28	0.06 to 0.31
Riboflavin (mg)	0.048	0.03 to 0.06	0.21 to 0.74
Niacin (mg)	0.854	0.6 to 1.09	1.3 to 2.8
Ascorbic acid (mg)	20.6	14.9 to 50	60 to 370
Vitamin A (µg)	---	5.0 to 35.0	8300 to 11800
Minerals			
Calcium (mg)	16	19 to 176	34 to 708
Phosphorus, total (mg)	27	6 to 152	27 to 211
Ca/P	0.6	1.6 to 5.48	2.5
Iron (mg)	0.27	0.3 to 14.0	0.4 to 8.3
Potassium (%)	---	0.25 (0.72)	0.35 (1.23)
Magnesium (%)	---	0.03 (0.08)	0.12 (0.42)
Copper (ppm)	---	2.00 (6.00)	3.00 (12.0)
Zinc (ppm)	---	14.00 (41.00)	71.0 (249.0)
Sodium (ppm)		76.00 (213.00)	51.0 (177.0)
Manganese (ppm)	---	3.00 (10.00)	72.0 (252.0)

Source: United States Department of Agriculture (USDA) (2009).

Table 2. Nutritional value after processing 100 g of cassava root.

Nutrient	Whole root	Peeled root	Boiled root	Bˆaton or Chikwangue	Gari	Flour (retting and no peel)	Flour (retting and peel)	Washed cooked
Wet root (g)	100	77.0	87.6	38.5	49.2	25.3 to 29.6	27.9 to 34.0	66.8
Dry matter (g)	40.0	32.3	28.3	21.6	29.7	21.3 to 25.6	20.8 to 28.7	19.0
Calories	157	127	112	86	119	85 to 102	83 to 115	76
Protein (g)	1.0	0.48	0.38	0.18	0.37	0.16 to 0.22	0.26 to 0.51	0.16
Fat (g)	0.1	0.1	0.04	0.02	0.2	0.04 to 0.06	0.04 to 0.12	0.03
Carbohydrates(g)	37.9	31.0	27.4	21.2	28.8	20.9 to 25.1	20.3 to 28.1	18.8
Fiber (g)	1. 3	0.6	0.5	0.4	0.6	0.4	0.3 to 0.6	0.3
Ash (g)	0.90	0.57	0.46	0.21	0.34	0.16 to 0.19	0.24 to 0.50	0.06
Calcium (mg)	26	13	12	7	10	6.0 to 8.0	7.0 to 15.0	11
Phosphorus (mg)	47	39	31	13	18	9.0 to 11.0	10.0 to 21.0	7
Iron (mg)	3.5	0.4	0.4	3.1	1.5	0.2 to 0.7	0.8 to 11.9	0.2
Thiamin (µg)	72	31	20	10	18	6.0 to 12.0	13	3
Riboflavin (µg)	34	18	16	21	15	10.0 to 12.0	8.0 to 21.0	6
Niacin (mg)	0.73	0.52	0.41	0.16	0.33	0.11 to 0.18	0.17 to 0.37	0.03
Vitamin C (mg)	33	20	1	1	2	0	0	0

Source: Institute of Food Technologists (2009).

and thus calories. Although raw cassava root contains significant vitamin C, it is very sensitive to heat and easily leaches into water, and therefore almost all of the processing techniques seriously affect its content (Julie et al., 2009). Boiled cassava, *gari*, and products resulting from retting of cassava root with peel, retain thiamin and niacin better than products obtained after retting of shucked cassava roots, smoked-dried flour, and *medua-me-mbong*. Riboflavin is well retained in boiled cassava, *gari*, and smoked-dried cassava flour obtained after retting of cassava root with peel in contrast, the losses of vitamin B2 (riboflavin) (Julie et al., 2009).

POSTHARVEST HANDLING AND STORAGE

Cassava is harvested by hand by raising the lower part of the stem and pulling the roots out of the ground, then removing them from the base of the plant. The upper parts of the stems with the leaves are plucked off before harvest. Cassava undergoes postharvest physiological deterioration (PPD) once the tubers are separated from the main plant. The tubers, when damaged, normally respond with a healing mechanism. However, the same mechanism, which involves coumaric acids, initiates about 15 min after damage, and fails to switch off in harvested tubers (Sánchez et al., 2010). It continues until the entire tuber is oxidized and blackened within two to three days after harvest, rendering it unpalatable and useless. PPD is one of the main obstacles currently preventing farmers from exporting cassava abroad and generating foreign exchange income. Post-harvest strategies include the development of effective and simple machines and tools that reduce processing time and labour, and production losses. With these machines, losses can be reduced by 50% and labour by 75% (Sánchez et al., 2010). Cassava can be preserved in various ways such as coating in wax or freezing. Plant breeding has resulted in cassava that is tolerant to PPD. (Sánchez et al., 2010) identified four different sources of tolerance to PPD. One comes from Walker's Manihot (*M. walkerae*) of southern Texas in the United States and Tamaulipas in Mexico. A second source was induced by mutagenic levels of gamma rays, which putatively silenced one of the genes involved in PPD genesis. A third source was a group of high-carotene clones. The antioxidant properties of carotenoids are postulated to protect the roots from PPD (basically an oxidative process). Finally, tolerance was also observed in a waxy-starch (amylase-free) mutant (Sánchez et al., 2010). This tolerance to PPD was thought to be co-segregated with the starch mutation, and is not a pleiotropic effect of the latter (Sánchez et al., 2010).

Two types of post harvest 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. The former 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 vascular streaking. These initial symptoms are followed by a more general discoloration of starch-bearing tissue (Andrew, 2002).

Processing techniques of cassava root

Fresh cassava roots cannot be stored for long because they rot within 48 h of harvest. They are bulky with about 70% moisture content (Hahn, 1994). Therefore, cassava must be processed into various forms in order to increase the shelf life of the products, facilitate transportation and marketing, reduce cyanide content and improve palatability. The nutritional status of cassava can also be improved through fortification with other protein-rich crops. Processing reduces food losses and stabilizes seasonal fluctuations in the supply of the crop. Traditionally, cassava roots are processed by various methods into numerous products and utilized in various ways according to local customs and preferences. Traditional cassava processing methods in use in Africa probably originated from tropical America, particularly north-eastern Brazil and may have been adapted from indigenous techniques for processing yams (Hahn, 1994). The processing methods include peeling, boiling, steaming, slicing, grating, soaking or seeping, fermenting, pounding, roasting, pressing, drying, and milling as shown in Figure 1.

Storage techniques

The storage of agricultural raw materials is an essential aspect of food processing that ensures that food remains available even in time of scarcity (Osunde and Fadeyibi, 2011). Traditional marketing and storage systems have been adapted to avoid root perishability (Aristizabal and Sánchez, 2007). These adaptations include processing centered in proximity to the areas of production to ensure a daily supply of raw material, processing into storable forms (through sun drying, fermentation, etc.) at the farm level and the common practice of trading of small quantities of roots (Weham, 1995; Westby, 2002). A common way of avoiding root losses due to PPD is to leave the roots unharvested in the soil after the period of optimal root development, until the roots can be immediately consumed, processed or marketed. Cassava roots are known to last in soil up to three years. This strategy has disadvantages because large areas of land are used by the standing crop, unavailable for additional agriculture production. Furthermore, even though the roots may increase in size they become more woody and fibrous, decreasing palatability and increasing the cooking time, respectively, if left longer than the optimal

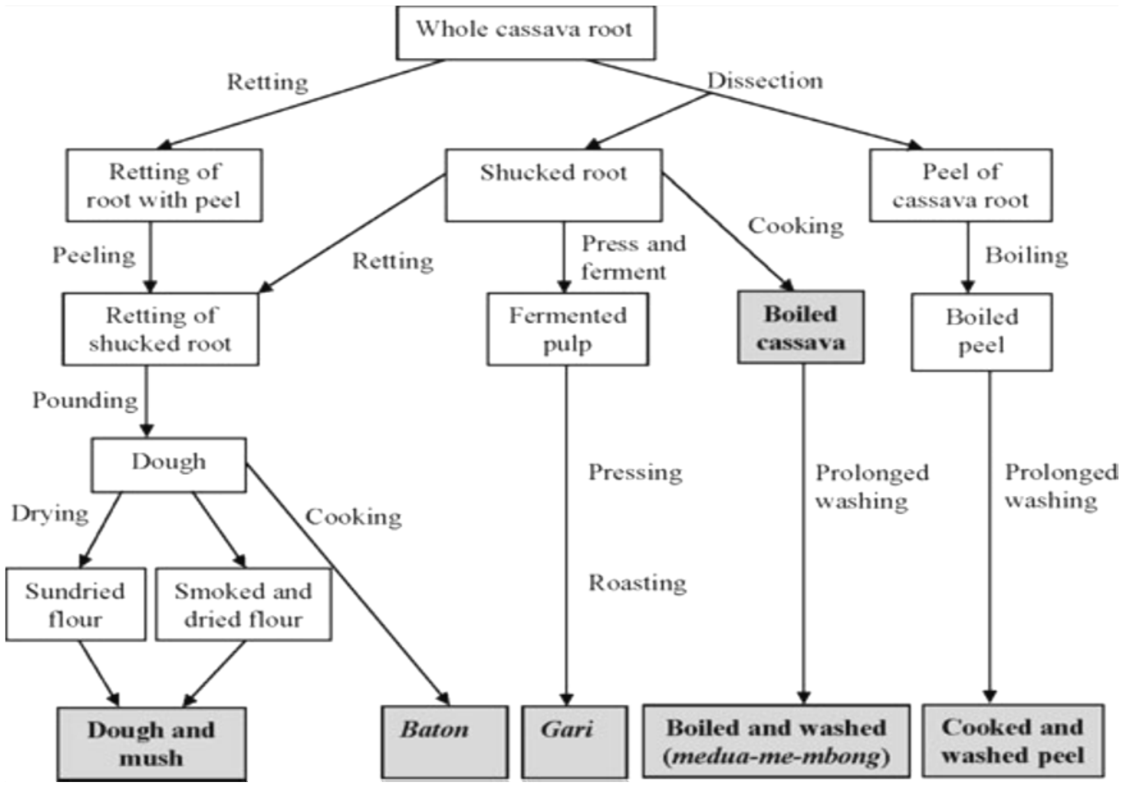

Figure 1. Different processing techniques for whole cassava root. The edible forms of cassava root are shaded in gray adapted of Julie et al. (2009).

harvest time of 10 to 12 months after planting. Another negative effect occurring due to extensive in-field storage of cassava roots is their increased susceptibility to attack by pathogens as well as the reduction of extractable starch (Wenham, 1995; Ravi et al., 1996).

Fresh cassava roots cannot be stored for long because they rot within 24 to 48 h of harvest. They are bulky with about 70% moisture content, and therefore transportation of the tubers to urban markets is difficult and expensive. Good storage depends on the moisture content of the products and temperature and relative humidity of the storage environment. The moisture content of gari for safe storage is belong 12.7% (Osunde and Fadeyibi, 2011), when temperature and relative humidity are above 27°C and 70% respectively, gari goes bad. The type of bag used for packing also affects shelf life depending on the ability of the material to maintain safe product moisture levels. During the last twenty years there have been some developments in improving storage methods capable of extending the shelf life of fresh cassava roots by at least two weeks. These, amongst other advantages, make it possible to market the crop further and give an increased margin to the opportunity of holding stocks of fresh cassava, even for few days, at a processing plant. A joint project between the National Resources Institute, and Centro Internacional de Agricultura Tropical (CIAT) studied alternative storage methods to the traditional reburial procedures. These included storage in pits, in field clamps and in boxes with moist sawdust. All the storage methods investigated favoured curing conditions in a high humidity and high temperature environment in order to slow down the rates of physiological and microbiological deterioration (Osunde and Fadeyibi, 2011).

However, to be successful they all require careful harvesting and selection of the roots prior to storage, since curing is not effective if root damage is extensive (Crentsil et al., 1995). Storage in boxes lined with moist sawdust or wood shavings involves putting alternative layers of sawdust and cassava roots, starting and finishing with a layer of sawdust. As an alternative to sawdust, wood shavings or any other suitable packing material can be used. However, the packing material must be moist but not wet. Physiological deterioration occurred if the material was too dry and microbial decay accelerated when it was too wet. In Uganda this storage method was tested in combination with the lining of box with plastic (Nahdy and Odong, 1995). The study indicated that 75% of the roots remained healthy after four weeks in store, provided the roots were packed immediately on the day of harvest. With a delay of one day only 50% of the roots were rated as acceptable. This technique has been used for some export markets but the higher transport cost involved because of the box

Table 3. Demand estimates of cassava supply in Nigeria.

Product	Demand estimate (Tons)	Substitution (%)	Potentials (Tons)	Fresh root (Tons)	Utilization estimate (MT)
Flour	7,525,000	30	2,257,500	22,575,000	7,537,479.95
Starch	4,970,000	50	2,485,000	12,425000	1,076,000
Livestock feed	91,243,248	20	18,248,649.6	72,994,598.4	1,614,000
Ethanol	3,600,000	50	1,800,000	14,400,000	538,000
Total				10,765,479.95	

Conversion factor: 1 t of starch = 400 L Ethanol (98% efficiency). Starch: 5: 1 (raw: starch). Livestock: 4:1 (raw: chip). Land required: 356,250 ha@20 t/ha Conversion factor for ethanol: 1:8. Source: Personal Field observations, FAOSTAT (2011) Phillips et al. (2004) and Kormawa et al. (2003).

containers has precluded its use for domestic market (Osunde and Fadeyibi, 2011).

Storage in plastic bags or plastic film wraps appears to be the most practical and promising method of storing cassava roots intended for the urban markets. A number of studies have shown that cassava roots treated with an appropriate fungicide and kept in an airtight plastic bag or a plastic film wrap can be stored for two to three weeks (Osunde and Fadeyibi, 2011).

Some modern methods, such as refrigeration, deep freezing, waxing, controlled atmosphere and chemical treatments, have been suggested for the storage of fresh cassava. Freezing and waxing have been used primarily for export markets in Europe and America, where the customers of African and Latin American origin are prepared to pay high prices. These techniques require specialized equipment and skills and are very capital intensive (Crentsil et al*.,* 1995). A more common modern method of limiting PPD is covering cassava roots with paraffin wax by dipping the root in paraffin wax (at a temperature of 55 to 65°C for a few seconds) after treatment with fungicide. Use of wax has been reported to prolong shelf-life of cassava roots up to 2 months (Ravi et al., 1996; Aristizabal and Sánchez, 2007). Cassava roots can also be stored for 2 weeks between 0 to 4ºC without any internal deterioration. The most favourable temperature for storing fresh cassava is 3°C but after 4 weeks microbial infection takes place and will increase with subsequent storage time. However, even after 6.5 months of storage between 0 to 4°C, the part of the root without decay usually is in excellent condition and is suitable for human consumption (Ravi et al., 1996; Oirschotet al*.,* 2000). At temperatures above 4°C roots develop the PPD symptoms more rapidly and have to be discarded after 2 weeks of storage (Ravi et al., 1996). Alternatively, entire roots or more usually pieces of root can be stored frozen under deep-freeze conditions in polyethylene bags and the roots were quite palatable after thawing, although some sponginess was present, and was able to be kept for a further 4 days. This technique is used at a commercial scale in many Latin American countries such as Brazil, Colombia, Costa Rica and Puerto Rico (Ravi et al., 1996).

DEMAND ESTIMATES OF CASSAVA SUPPLY IN NIGERIA

The tolerance of cassava to extreme stress conditions, its low production resource requirements, its biological efficiency in the production of food energy, its availability throughout the year and its stability for farming systems, will make cassava products gain more popularity in Nigeria (Kormawa et al*.,* 2003) (Table 3).

INDUSTRIAL PRODUCTS FROM CASSAVA

Four primary industrial products from cassava stand out as important for Nigeria. These are (a) cassava flour, (b) crude ethanol, (c) native starch, and (d) animal feed/cassava chips and pellets. These products are commonly traded and show the highest potential for growth in demand, and are associated with medium and large scale processing.

In the domestic market, industrial cassava products compete with traditional cassava products, mainly gari. Furthermore, each of the main industrial products (cassava flour, chips for animal feed, chips for food grade ethanol, and cassava starch) faces competition from (a) identical imported products, and (b) substitute products that are either being imported or locally grown. For domestic cassava flour the main competitive product is wheat flour. For cassava chips/pellets it is feed grains. For ethanol it is ethanol from other sources, and for starch it is corn/maize starch. Quite clearly, significantly lowering the cost of raw materials (ex-factory price) would greatly reduce the cost of the final product, making them more competitive. One strategy to achieve this is the vertical integration of commercial farms to each processing plant.

SECONDARY PRODUCTS FROM CASSAVA

Cassava can be processed into various secondary products, including modified cassava starch, glucose syrup, extra neutral alcohol, noodle, bakery and confectionery industries, meat and textile processing. It is also industrially processed as a raw material in the coating of pharmaceutical products, the manufacture of glues and adhesives and oil drilling starch (EFDI-Techno Serve, 2005).

Glucose syrup: is a concentrated aqueous solution of glucose maltose and other nutritive saccharine made from edible starch. Glucose or dextrose sugar is found naturally in sweet fruits such as grapes or honey. It is less sweet than sucrose (cane sugar) and is used in large quantities in fruits, liquors, crystallized fruits, bakery products, pharmaceuticals, and breweries.

Noodles: are a long thin extruded food product made from a mixture of flour, water, and eggs usually cooked in soup or boiling water (Sanni, 2005). At 12.5%, cassava starch/flour forms an integral part of the final product.

Cassava based adhesives: like the cereal starch adhesives, are of three main types:

i) *Liquid starch adhesives* are supplied by the adhesives manufacturer in liquid form usually in plastic or lined metal drums, jerry cans and bottles.
ii) *Pre-gel starch adhesives* are produced in dry flakes and milled to specific particles sizes. They are packed in waterproof lined multi-wall paper bags/sacks and are very suitable for export.
iii) *Dextrin based adhesives* are delivered to consumers in liquid and dry forms depending on specification and requirement. The liquid dextrin adhesives are packed as the liquid starch adhesives, while the dry dextrin adhesives are packed as the milled pre-gel adhesives. Dry dextrin adhesives are very suitable for export as intermediate raw materials used especially in Europe and America by the food and industrial companies.

High Quality Cassava Flour (HQCF)

Nigeria imports over one million tonnes of wheat annually. At 10% substitution of cassava flour in wheat flour and with the current national demand, 300,120,000 metric tonnes of HQCF (assuming the national demand for wheat flour is 1.2 million tonnes), is required (IITA, 2011). 30% of the total wheat can be replaced by cassava flour in bread making, and 100% cassava flour is currently being used in pastries and confectioneries (Onabolu et al*.,* 1998). However, with poor regulation and standardization, some bakeries have complained about problems: including presence of impurities such as sand; odour; shorter product shelf life (e.g. biscuits); brittleness; gradual change of colour (biscuits turning pale); unreliable supply; poor final product quality in cases where the cassava flour had partially fermented. With other domestic uses for cassava flour in snacks, a more realistic estimate for the annual demand of cassava flour is therefore 250,000 to 300,000 MT (Cassava Master Plan, 2006), a figure impossible for small holders to supply. The process of flour production is described below.

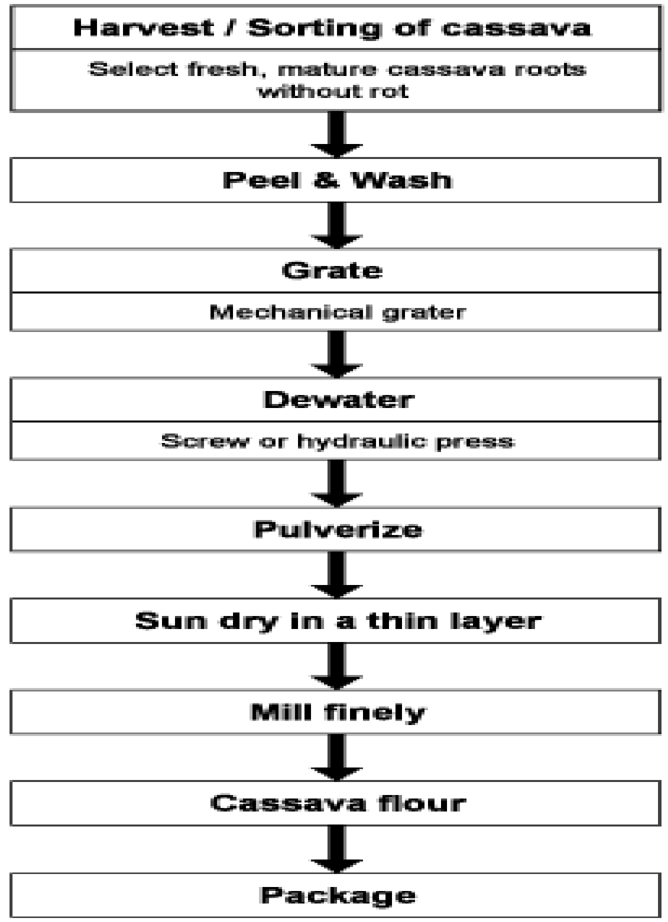

Figure 2. Process flow chart for high quality cassava flour (Cassava Master Plan, 2006).

Cassava chips

Cassava chips are dried irregular slices of roots, which vary in size but should not exceed 5 cm in length (CIAT, 2004). The tuberous roots, either peeled or unpeeled, are cut up into chips (cossettes) and dried. Chips from peeled roots are used for human consumption and in animal feed industry and generally store better than flour (IITA, 1990). Chips are the most common form in which dried cassava roots are marketed and most exporting countries produce them. The standard method of processing chips consists of peeling, washing, chipping the cassava roots, and then sun drying the slices. The recovery rate of chips from roots is 20 to 40% depending on the initial dry-matter content of the cassava roots and the final moisture of the chips (Cassava Master Plan, 2006) (Figure 2).

In Nigeria, cassava chips were processed into animal

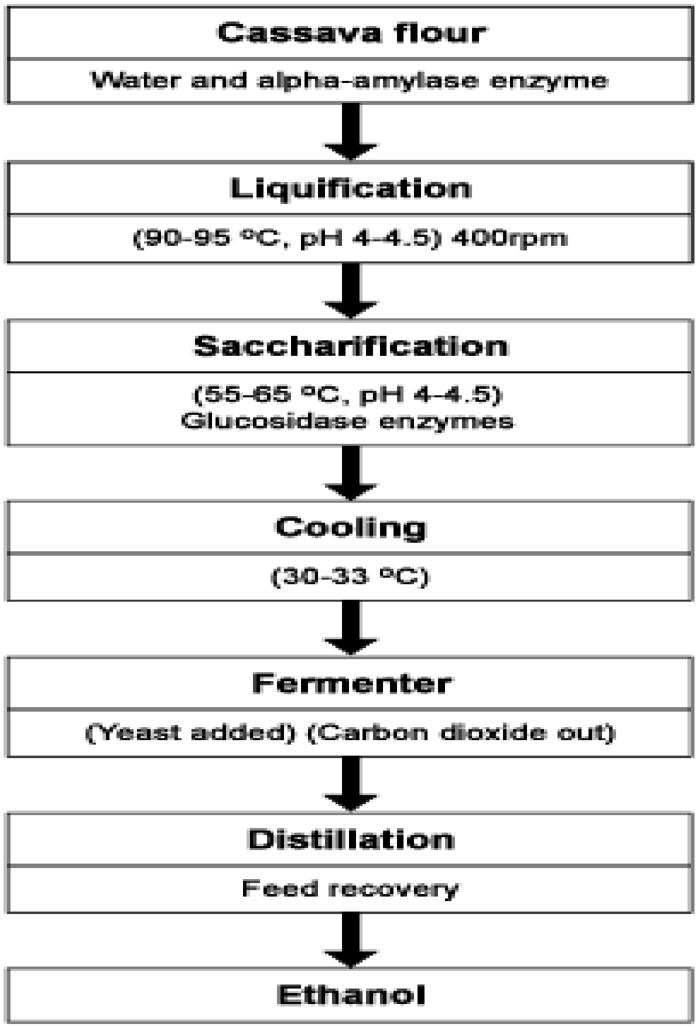

Figure 3. Flow chart showing the production of ethanol from cassava flour (Cassava Master Plan, 2006).

feed and some animal feed millers continued the practice until the late 90s when the price of cassava became too expensive vis-à-vis the price of maize. Presently, no major livestock feed mill uses cassava as a raw material, although smaller mills and large farms that blend their own feed use cassava chips or meal when these are locally available at low prices. The livestock sector in Nigeria is rapidly expanding and a continued demand for animal feed is predictable. In view of the relatively high-income elasticity for meat products, it is likely that this trend will continue during the remainder of this decade. Processing cassava chips into cassava pellets will further reduce transport costs and enhance product quality.

Cassava pellets for animal feed

Substituting maize with cassava in animal feed have been made using linear programming, saving of up 10% in poultry feed costs and about 20% for pig feed (Cassava Master Plan, 2006). With the Nigerian livestock industry uses up to 1.2 metric tonnes of maize annually (Cassava Master Plan, 2006), substituting 10% of this figure with cassava would involve setting up of at least 200 cassava chip making factories processing about 10 tonnes of cassava roots per day (Cassava Master Plan, 2006), Pellets can be made either from cassava chips or flour. An indigenous Nigeria company, B & T Ventures, Ibadan, in collaboration with the cassava project at IITA, has designed and created a pelleting machine that can produce three different types of cassava pellets: hard, soft, and floating. The hard pellets are used for feeding poultry, the soft ones for feeding ruminants, and the floating ones for feeding fish. However, the machinery is still under R & D and is not as efficient as imported pelleting machines.

Ethanol

Ethanol is produced by the fermentation of sugar related materials such as molasses and sugar juice, or starchy materials. Cassava stands as one of the richest fermentable substances for the production of crude alcohol/ethanol, with dry chips containing up to 80% of fermentable substances (starch and sugars) (Cassava Master Plan, 2006). The process of cassava based ethanol production is described in Figure 3.

Tapioca

In Nigeria, this is made from partly gelatinised cassava starch, (although the cassava crop itself is called tapioca in some places, heat treated to a moist mash in shallow pans. Its shapes are irregular lumps called flakes, or perfectly ground beads. It is consumed in many parts of West Africa, soaked or cooked in water with sugar and/or milk added. High labour processing steps make it quite expensive (Sanni et al*.,* 1992).

High quality garri

With a share of 70% of all cassava fresh roots harvested, gari will continue to dominate the cassava sector in the short term. The growth rate of gari has been put at least 4 to 6% per annum, primarily due to population growth and increasing urbanization, and export to the regional West African market. It already provides livelihoods to more than 5 million farmers and processors (often poor rural women) in Nigeria, as well as to numerous equipment manufacturers, wholesale and retail traders, and transporters. In addition, small-scale garri processing has gradually become the main source of non-farm rural employment in many countries. The process flow chart is described in Figure 3.

Sweeteners

Cassava starch and HQCF can be used as raw material for sweeteners, primarily high fructose syrup (HFS), glucose, and sorbitol. Sweeteners are obtained by hydrolysis of cassava starch or flour or wet cake, to produce glucose, which is further purified to produce HFS or hydrogenated to produce sorbitol. One ton of starch yields 900 kg of glucose, 550 tons of HFS (55% purity), and 1.1 ton of sorbitol (70% purity) (Cassava Master Plan, 2006). The annual demand for these sweeteners in Nigeria is: 150,000 tons of HFS, as part replacement for imported sugar in the soft drink and juice industry, 40,000 tons/year of glucose, and 14,000 tons of sorbitol (FAO, 2011). The sweetener industry is a strong market that is expected to grow by 50% over the next ten years. Ekha Agro Nigeria Limited is currently the only cassava processor, producing sweeteners, liquid glucose, from cassava for supply to Guinness Plc (FAO, 2011).

CONCLUSION

The research in cassava processing has established the fact that there is a lot more in cassava than starch. The nutritional quality content in cassava can be enhanced by developing new varieties by biofortificaton, cassava could be source of raw materials for a number of industrial products example include, the starch, flour and ethanol. The production of cassava is relatively easy as it is tolerant to the biotic and edaphic encumbrances that hamper the production of other crops. Cassava has a shelf life that is generally accepted to be of the order of 24 to 48 h after harvest. Rapid postharvest deterioration means that processing is more important than for any other root crops. Processing reduces food losses and stabilizes seasonal fluctuations in the supply of the crop. Processing cassava can affect the nutritional value of cassava roots through modification and losses in nutrients of high value. Although raw cassava root contains significant vitamin C, it is very sensitive to heat and easily leaches into water, and therefore almost all of the processing techniques seriously affect its content.

Conflict of Interest

The authors declare that there is no conflict of interest.

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