10.1
Cassava Flour and Starch: Processing Technology and Utilization

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10.1.1 Introduction

Cassava (*Manihot esculentus*, Crantz) is one of the root crops with growing food and industrial applications. It has been one of the mainstays of several tropical and sub-tropical countries of the world. According to FAO statistics, the world's cassava production had been on the increase from about 176–277 metric tons per year from the years 2000–2013. Africa contributed between 54 and 58% of the world's cassava within these periods (Figure 10.1.1). Nigeria is the largest cassava root producer in the world. The impacts of cassava on the economies of different countries have changed in the last two decades. Previously, in some economies, it was an economic crop while in some others it constituted merely a poverty alleviation crop. Except in a very few countries, cassava has assumed a prominent position as an industrial crop with constantly growing utilization avenues.

The roots are highly perishable due to their high moisture content at harvest. Besides the advantage of preserving the root, processing is also used to add value to the raw roots by converting them to several primary and secondary products of varying economic importance. Primary products are those derived from raw roots without extensive transformation (or modification) of cassava tissue via chemical, enzymatic and microbial processes. Primary processing of cassava roots merely involves physical modification to achieve either root preservation, enhanced handling or storage stability. Such products are either consumed by humans or animals, or

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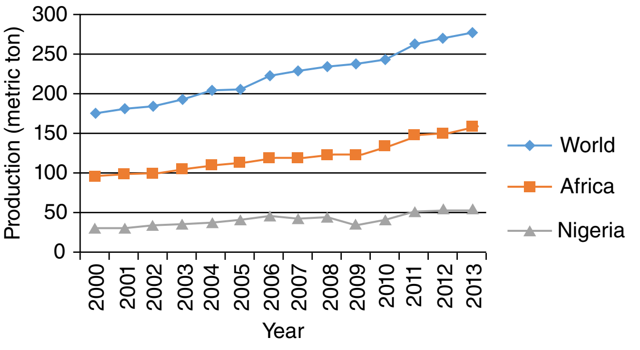

Figure 10.1.1 Production of cassava between 2000 and 2013 (source: FAO, 2014).

used as raw materials in some other processing applications. These include mainly chips (dried and boiled), flours and starch. The proportion of cassava root processed to specific end products differ from region to region. Overall, the extent, direction and capacity of cassava roots-value addition in any country depends on the level of economic and technological advancement.

Flours and starch powders are the two major primary products from cassava roots traded world-wide. They are essentially dried products, often packaged, stored or marketed at low moisture levels (10–14%, wet basis). Numerous studies aimed at improving their quality and expanding their utilization have been conducted world-wide, especially in regions where cassava potentially have comparative economic advantaged over other root crops. This chapter seeks to describe the existing and emerging cassava processing technologies, and utilization of cassava flour and starch.

10.1.2 Cassava Flours

Cassava flour (CF) refers to the dry, fibrous and free-flowing particulate product obtained from cassava roots. It is either prepared from milled dried chips or wet mash. Mashing of cassava root can be achieved by grating, pounding or milling of peeled roots. The prepared mash may either be fermented or unfermented. When the unfermented mash is dried and milled, it gives rise to a bland, odorless, white or off-white particulate product also known as high-quality cassava flour (HQCF). The flours from fermented cassava root are also known as *lafun*, *fufu* or *pupuru* in Nigeria. Report of the Collaborative Study of Cassava in Africa (COSCA) indicated that CF and chip production consumed about 45% of cassava roots produced in the sub-Saharan African region (Nweke, 1994).

10.1.2.1 Processing Technology

The main processing steps in CF production are summarized in Table 10.1.1. Similar to other sub-Saharan African countries, the CF processing technology has experienced tremendous improvement in Nigeria over the last four decades. Due to the changing status of cassava from poverty alleviation to an economically important crop, there

Table 10.1.1 Description of technological effect of processing steps during CF manufacture

Processing step	Technological effect	Authors and years of study
Root washing	Mainly to remove the adhering dirt and sand particles from the root surface prior to peeling. It is done with clean water.	–
Peeling	To separate the flesh from skin.	Ezekwe (1976); Igbeka (1985); Ohwovoriole *et al.* (1988); Oluwole and Adio (2013)
Washing	To further clean the peeled root from adhering dirt and incompletely removed skin during peeling	–
Root Size reduction	Might involve chipping, chunking or grating of peeled cassava root. The grating process leads to lower particulate wet mash while chipping and chunking leads to larger particulates more difficult to dry.	Jones *et al.* (1994) Doporto *et al.* (2012)
Fermentation	Allowing the wet mash to ferment for 3–5 days in sacks or fermentation vats	Westby (1991); Okolie and Ugochukwu (1988); Ampe *et al.* (1995)
Dewatering (or Pressing)	This is done to remove excess water from the wet cassava mash after root grating and/or fermentation, It gives rise to wet cake. This makes handling easy and enhances drying of the wet mash.	–
Drying	Wet cake is pulverized and either sun dried or flash dried to moisture content below 12%. It gives rise to dry and coarse cassava meal.	Shittu *et al.* (2001); Osundahunsi (2005); Bindzi *et al.* (2014).
Dry Milling	Dried meal is milled to fine particulates (flour) also known as CF or high quality cassava flour if the whole process is completed within 24 h.	Shittu *et al.* (2002); Adesina and Bolaji (2013); Defloor and Delcour (1993)

has been a shift in the level of cassava processing technology. Nowadays, improved (mechanized) processing techniques are now replacing existing manual operation. The greatest drudgeries of manual peeling, size reduction, pressing, drying and milling have now been removed by the advent of various mechanical devices that perform these operations. It has given an opportunity to increase the throughput of many plants as well as improving the quality of product.

Cassava Peeling Peeling of cassava roots is one of the most tedious unit operations during cassava processing. It is done to remove the dark, rough skin. Women and children are the ones mainly involved in carrying out this operation by using sharp knives. The manual peeling is slow and burdensome due to the irregular shapes and sizes. The peel, which consists of periderm and cortex, also varies in thickness, texture and strength. The manual peeling operation is still predominantly used in most cottage, micro and small cassava processing outfits. Research efforts over the past four decades have been devoted to development of mechanical means of peeling cassava roots. Various designs of peelers have since been reported (Adetan *et al.*, 2006; Ezekwe, 1976; Igbeka, 1985; Ohwovoriole *et al.*, 1988; Oluwole and Adio, 2013). The peeling is actualized by either abrasive or cutting mechanism. About 75–97% peeling efficiencies have been reported for these designs. Use of abrasive peeling requires more water for washing than cutting methods. Although chemical and steam peeling methods used for potatoes have been tried for cassava peeling, the ineffectiveness and attendant quality issues have not made them satisfactory for industrial cassava processing. Use of lye (hot sodium hydroxide solution) to loosen and soften the skin of cassava root requires longer immersion time. This consequently causes objectionable heat rings in cassava flesh as well as starch gelatinization (Igbeka, 1985), making chemical peeling unsuitable for food and starch manufacture.

Size Reduction Fresh cassava roots are subjected to size reduction operations like chipping, mincing and grating (or rasping) to enhance subsequent unit operation like dewatering (pressing), drying, fermentation and starch extraction. The old-fashion method of manually grating cassava root is no longer practiced. Mechanical graters are now available in different designs and capacity (Figure 10.1.2). Size reduction also enhances biochemical detoxification of cassava roots. It breaks up tissue to release natural enzymes that catalyze conversion of toxic cyanogenic glucosides in cassava roots (linamarin and lotaustralin) to less toxic materials (glucose and cyanohydrin) in the presence of water. The cyanohydrin is further degraded to a ketone and hydrocyanic acid. Jones *et al.* (1994) demonstrated that mincing of cassava root caused complete degradation, while rasping and chipping caused 70–80% and 30% degradation of the glycosides, respectively. Besides their different influences on root detoxification, size reduction methods are also appropriate methods to achieve subsequent operations like drying and milling. Grated or retted pulps are more easily dewatered, dried and detoxified than chips, due to larger surface areas presented by the latter than the former. Literature data on the comparative effects of chipping, mincing and grating of root on the process (or energy) efficiency and quality of dried cassava products like flour and starch is generally deplete. Doporto *et al*. (2012) reported that the size reduction method of cassava root caused significant difference in the color of unfermented cassava flour. Grated cassava root resulted in higher lightness than sliced (chipped) root.

Most graters and raspers are batch motorized forms of equipment. The design of these size reduction items of equipment varies mostly in terms of the configuration of the grating unit. A manual rasper consists of a stationery grater/grinding stone against which the roots are rubbed to obtain a pulp, whereas a small-scale machine consists of a high-speed rotating wooden drum with a crushing surface fixed onto it. Nanda *et al.* (2004) developed a primary rasper with saw tooth blades for cassava starch extraction, which had a capacity ranging from 360–385 kg h^{-1}. Sheriff and Balagopalan (1999) described a multipurpose starch extraction plant of lesser capacity (75–125 kg h^{-1}) and evaluated the performance of the machine for various tuber crops. Sajeev and Balagopalan (2005) developed a multipurpose mobile starch extraction plant for the *in situ* starch extraction in villages for cassava, sweet potato and elephant foot yam. Capacity of the machines varied from 120–200 kg h^{-1} and the rasping effect from

(a) (b)

Figure 10.1.2 Some mobile micro scale cassava processing units (a) mobile cassava graters; (b) mobile batch mechanical press (source: Fieldwork, 2010).

40.32–61.10%, depending on the type of tuber crop. In large-scale modern starch factories, the Jahn-type raspers, consisting of a rotating drum with longitudinally arranged saw tooth blades around the periphery at 10 mm apart, has been widely used (Balagopalan *et al.*, 1988; Nanda and Kurup, 1994; Sheriff *et al.*, 2005).

Fermentation Fermentation is the most prominent processing operation applied to make edible products from raw cassava roots. The two types of cassava root fermentation practiced are solid state (SSF) and submerged fermentation (SMF). Both SSF and SMF involve activities of lactic acid bacteria (LAB). SSF is often precluded by root grating to give a cassava mass that is heaped up in the fermenter or tied in sacks and allowed to ferment for 3–5 days. However, SMF involves soaking of whole root or its chunks in water for 3–5 days. Apart from root softening, development of flavor is a common phenomenon during SSF of wet cassava meal for producing *gari* – a product commonly consumed in West Africa. The root may also be submerged in water for the purpose of retting prior to further processing. It has also been established that in both processes, the role played by microorganisms in cassava root fermentation is very significant. For example, Westby (1991) investigated the ability of important microorganisms isolated from two major classes of fermented cassava products (acidic grated roots and acidic soaked roots) to hydrolyze linamarin. LAB were the commonest organisms in each product. About 64% of the LAB was capable of causing significant reduction of the cyanogens in the respective products. Apart from detoxification, fermentation also causes significant root softening (or retting) of cassava tissue during submerged fermentation.

Okolie and Ugochukwu (1988) studied the activities of cell wall degrading enzymes isolated from *Citrobacter freundii* in cassava fermentation. The activities of polygalactorase, pectinase, cellulase, amylase and phosphorylase enzymes were monitored. It was shown that pectic enzymes were of primary importance and inhibition of alpha amylase and phosphorylase had no effect on root softening. Later, Ampe *et al.* (1995)

discovered that root softening was due to the combined action of both endogenous pectin methyl esterases and exogenous depolymerizing enzymes-mainly lyases.

CFs generally have low protein, which necessitates protein supplementation of most CF-based diets. Fungal-fermented CFs have been reported to have enhanced protein content (Akindahunsi *et al*., 1999; Oboh and Akindahunsi, 2003). However, some level of hepatotoxicity and cardiotoxicity was observed in rats fed with *Saccharomyces cerevisae* fermented CF (Oboh and Akindahunsi, 2005).

Dewatering or Pressing Only fermented or grated cassava mash is pressed to reduce the moisture content from an initial level to less than 30%, depending on the dewatering efficiency of the press. Following pressing, the bulkiness is reduced while subsequent handling and drying of the mass is enhanced. The press may either use the screw mechanism or hydraulic force. A simple, mobile, micro-scale hydraulic press is shown in Figure 10.1.2b. There are many designs of the presses. Their capacities vary with processing scale. Manual presses are used by micro- and small-scale processors. In somnnwabueze, medium and most large processing factories, automated presses are used. The efficiency of screw presses generally are lower than hydraulic presses.

Few research efforts have been paid to development of more efficient cassava mash dewatering systems. Olusegun and Ajiboye (2009) reported the design and fabrication of a vertical double squeeze cassava pulp dewatering machine to handle about 200 kg or 4 bags of cassava pulp per batch. The dewatering was achieved in 33.72 minutes. This machine was 7 times quicker than the IITA multi-purpose press and 40 times quicker than the local method of dewatering (IITA, 1990).

Kolawole *et al*. (2012) reported the development of an integrated machine capable of combining wet cassava mash conveying, dewatering, pulverizing and sifting in one machine unit. The machine was capable of reducing the moisture content of the pressed mash from 68% to about 47% (wet basis). However, the higher conveyor screw speed led to increased product temperature. Continuous operation of the machine could increase the temperature of the mash to a level that could lead to starch gelatinization, which could be detrimental to the product quality.

Drying (or Dehydration) Dehydration or drying is often used towards the end of CF processing to finish up with a shelf stable product. The moisture content of wet chips or mash is reduced by drying to about 10–14% on a wet weight basis after drying. The wet chips or mash may be sun or solar dried on a small scale to deliver between 50 and 100 kg per day. Although they are cheaper alternatives, their capacity and throughput are smaller, making them only suitable for small-scale processing outfits. Smoke dryers are also used mainly at the household level to produce *pupuru* (Figure 10.1.3). This particular method of drying cassava mash makes the product unique among other cassava flours. The smoke drying method was originally used for drying fish. It was adopted by peasants and cottage processors for drying fermented cassava mash in the riverine areas of Nigeria and some West African countries due to non-conducive climatic situations that could support sun drying of food (Shittu *et al.*, 2005). The wet fermented cassava mash is molded into a balls of 1–2 kg weight and laid on racks under which smoky heat is supplied over 2–7 days, depending on heating rate (Figure 10.1.3). Dried or incompletely dried balls are also retailed by the roadside. The drying rate is slow and often leads to spoilage via mold growth. Spoilage organisms associated with this product are aerobic spore-forming and non-sporing bacteria, as well as potentially toxigenic molds such as *Aspergillus flavus* and *Penicillium sp.* (Shittu *et al.*, 2010b).

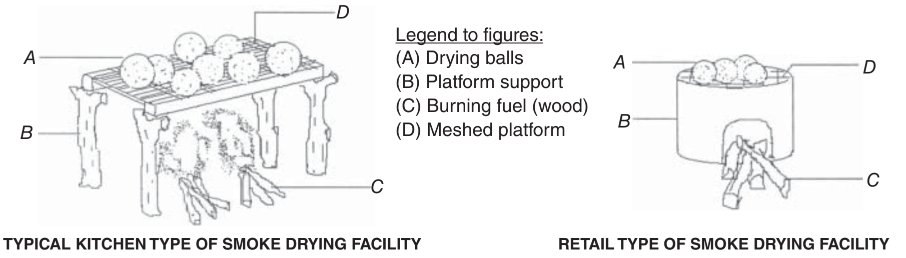

Figure 10.1.3 Typical smoke drying facility for dying fermented cassava mash in West Africa (source: Shittu *et al.*, 2005).

The presence of these aflatoxigenic organisms in the retailed and stored *pupuru* balls signals some public health concern.

Kiln drying as a form of smoke drying technology was evaluated as an alternative method for making *pupuru* balls (Shittu *et al*., 2001). Kiln drying resulted in faster moisture removal from the balls. The traditionally dried *pupuru* gave flour with the highest setback retrogradation. Similar observation was later reported by Bindzi *et al*. (2014). Flour from kiln-dried balls was more acceptable than the traditional and oven dried samples. The study recommended that energy efficiency of these methods be established. Osundahunsi (2005) compared the traditional smoke drying method with oven and solar-cabinet drying of *pupuru* ball. The smoke dried product was more acceptable than others in terms of aroma, as similarly reported by Shittu *et al*. (2001). The better aroma could be due to impregnation of the ball with some volatiles from the burning wood. Further studies are required to unravel the volatile composition of the product.

Due to recent advances in cassava-processing scales, some medium- and large-scale processors have now adapted some higher capacity artificial dryers such as cabinet, rotary and flash (pneumatic) dryers (Figure 10.1.4). These dryers are still currently used for batch production of cassava flours in Nigeria. Depending on design, flash dryers are capable of delivering 1–60 metric tons of dry product per 8 h working day. To date, the maximum throughput for a Nigerian designed flash dryer is still less than 3 metric tons per day. There are, however, few imported flash dryers capable of delivering 60 tons dried products per day. Not less than 100 units of such facilities are currently operating in Nigeria, mainly for cassava products. Nigerian flash dryers ordinarily use spent automobile (black) oil or diesel as fuel. The efficiency of a flash drying facility depends on variables such as number of cyclones, fuel burner efficiency, and feed moisture content among others.

Drying of cassava is a critical operation that affects the quality of the final product. Starch granular properties and by implication of the starch-based functional properties, cassava flour may be modified by the drying process (Maziya-Dixon *et al.*, 2005; Shittu *et al.*, 2001). However, this depends on the drying conditions such as drying temperature, drying time, drying method and so on. Higher temperatures and longer drying times lead to increased starch granular modification and change in starch-based functional properties.

Dry Milling Milling is an energy-intensive operation which leads to production of particulates size of less than 400 μm, referred as flour in many instances. Regardless

Figure 10.1.4 Flash dryer (source: Sanni *et al.*, 2006).

of processing scales, it is carried out mechanically with the use of milling machines. The most popular types of milling machines used are attrition and hammer mills (Nwaigwe *et al.*, 2012). A study of cassava processing machineries used in the Oyo State of Nigeria indicated that milling machines are the third-most popular after graters and pressing machines. Dry milling operations in the processing factories surveyed are manned mainly by males (Davies *et al.*, 2008).

Few studies have been conducted on dry milling of cassava. Nwaigwe *et al.* (2012) designed a mechanical mill for converting cassava chips into flour due to some ineffectiveness of existing machines to produce acceptable flour grade for the bakeries. The mill was based upon both an impact and shearing milling action, with a pneumatic conveying and classifying action. The modified milling gave an efficiency of 82.3% with fineness modulus of 0.31 and average particle size of 0.075 mm compared to 2.35 and 0.085 mm of an existing hammer mill, respectively.

The influence of moisture content on the dry milling characteristics of dried cassava chips was studied by Shittu *et al.* (2002). The amount of energy used in dry milling depends on the initial particle size of feed and moisture content. Increased feed size and moisture leads to higher milling energy consumption to produces flour of specific particle size.

The effect of milling was studied by Adesina and Bolaji (2013). Although the authors did not describe moisture content and size of the cassava chips milled, they reported that milling affected the flour yield and mill recovery. Moreover, the pin milling method gave complete flour yield and recovery. Similarly, differences in the dry milling procedure led to different compositional values. Defloor and Delcour (1993) reported that insignificant differences were found in the thermal and pasting properties of CF obtained from hammer, ball and roller milling of cassava chips at two moisture content levels (11.5 and 15.9%). However, milling cassava chips at 11.5% gave lower yield of break roll flour but higher yields of reduction roll flour than was obtained at 15.9% moisture.

10.1.2.2 Cassava Flour Properties

The various types of cassava flour-based products are listed in Table 10.1.2. Like any other food product, CF properties can be divided into physical, chemical, functional and microbial properties. Certain properties (also known as standard quality indices) are used to provide a guide in regulating local and international trades, only while others have been used to determine potential end uses of CF.

Properties Related to Industrial Standards and Specification Published documents to guide food trade within and across national boundaries, also known as food standards, are available for different raw and finished food products. Each country and region of the world is separately responsible for developing standards. The international quality standards for food products are developed by the Codex Alimentarius Commission (CAC). The African Organization for Standardization is responsible for development and harmonization of African Standards to enhance trading within the region. The general quality specification for raw and finished food products traded within Nigeria is provided by the Standards Organization of Nigeria (SON). There is some agreement between specification by Codex Standard (CODEX STAN 176-1989), African Standard (ARS 840: 2012) and Nigerian Industrial Standard (NIS 344: 1997) for edible cassava flour.

Table 10.1.2 The types of cassava products studied by previous authors

Flour Type	Specific product(s)	Authors
Fermented	Pupuru flour	Osundahunsi (2005)
	Fufu flour	Sanni *et al.* (2006)
	Fufu flour	Sanni *et al.* (1997)
	Pupuru flour	Shittu *et al.* (2001)
	Pupuru flour	Shittu *et al.* (2005)
	Dark cassava flour	Essers (1994)
	Yeast fermented cassava flour	Oboh and Akindahunsi (2003)
		Oboh and Akindahunsi (2005)
		Akindahunsi *et al.* (1999)
Unfermented	Tapioca flour	Chiste *et al.* (2012)
	Cassava flour	Aryee *et al.* (2006)
	Cassava flour	Ogbonna and Okoli (2010)
	Cassava flour	Hossen *et al.* (2011)
	Cassava flour	Defloor *et al.* (1995)
	Cassava flour	Derkyi *et al.* (2008)
	Cassava flour and gari	Bradbury (2005)
	Cassava flour and starch	Doporto *et al.* (2012)
	Cassava flour	Shittu *et al.* (2002)
Composite	Cassava-wheat flour composite	Shittu *et al.* (2015b)
	Cassava-wheat flour composite	Akinrele (1973)
	Cassava-wheat flour composite	Shittu *et al.* (2008)
	Cassava-wheat flour composite	Eggleston *et al.* (1993)
	Cassava-wheat-soybean flour composite	Oluwamukomi *et al.* (2011)

Table 10.1.3 Standards for CF

S. no.	Parameter	Standard
1	Moisture (max)	13%
2	Fiber (max)	2%
3	Ash (max)	3%
4	Fine flour	90% of CF passes through 0.6 mm sieve
5	Coarse flour	90% of CF passes through 1.2 mm sieve
6	Hydrocyanic acid (db, max)	10 mg/kg
7	Sulfated ash (max)	0.5%
8	Starch	65–70%
9	Total acidity	1%

Source: CAC, 1989; ARS (2012)

Codex Standards for edible CF stipulated that CF be free from abnormal flavors, odors and live insects, filth (impurities of animal origin, including dead insects). The various codex standards for CF are presented in Table 10.1.3.

Nigeria is distinctly known to have a history of producing and consuming some fermented CFs (*lafun, fufu and pupuru*) that have many similar characteristics (Shittu *et al.*, 2005). Out of these, fufu is the most commercially traded world-wide. However, to date, no local industrial standard is available for lafun and pupuru (*ikwurikwu*), probably due to their lower export (or commercial) values.

Physical Properties The color of CF is an important physical property that influences its acceptability and potential application. It varies according to root variety and processing method. The bitter cassava roots give whitish flours, whereas yellow fleshed roots give off white color. The color of CF may be measured instrumentally (using colorimeters) or may be assessed sensory-wise. The Hunter or CIE-Lab color indices are often used. Both color systems consist of lightness (L), greenness-redness (a) and blueness- yellowness (b) color spaces. It is often reported as whitish ($60 < L < 110$) with low yellowish tint ($12 < b < 15$), as found in flours from white fleshed roots (Shittu *et al.*, 2007). Some yellow fleshed or carotenoid cassava roots may have higher values for greenness and yellowness.

Pasting Properties The pasting properties of flour shows the behavior of its flour/water suspension when cooked. It indicates the potential end use of the flour for cooking purposes. The peak viscosity indicates the maximum viscosity attainable during cooking of flour suspension to near boiling point (95°C). Breakdown viscosity also indicates the stability of the paste when retorted or subjected to prolonged heating. Setback viscosity indicates tendency of the cooked paste to undergo retrogradation. The pasting temperature and peak time are both indices of ease of cooking amount of energy required to cook the aqueous suspension of the flour. The crop type, variety, particle size of flour, relative composition of starch, protein, fiber and fat affect the pasting characteristics. Table 10.1.4 shows the typical pasting behavior of flours from some roots and tubers. CF is known to have an intermediate thickening power among flours (Table 10.1.4). The pasting viscosity is slightly higher than the new cocoyam flour (*Xanthosoma sagittfolium*). According to Hossen *et al*. (2011), potato showed the greatest paste viscosity and the least hot paste stability among the different flours studied.

Table 10.1.4 Pasting properties of some flour from root and tuber crops

Crop	Peak Viscosity	Trough	Breakdown Viscosity	Setback Viscosity	Final Viscosity	Peak Time	Pasting Temp	Source
Dioscorea dumetorum	3180.5	1919.0	1261.5	2806.5	887.5	4.67	83.95	Abiodun *et al*. (2014)
Dioscorea alata	4115.0	2326.0	1705.0	4064.0	1750.0	4.87	68.40	Babajide and Olowe (2013)
Dioscorea rotundata	2544.0	1301.6	1241.0	2767.0	1469.3	5.74	880.85	Babajide and Olowe (2013)
Manihot esculenta (Min)	2596.8	627.6	1252.8	884.4	201.6	3.87	76.80	Shittu *et al*. (2008)
Manihot esculenta (Max)	3678	1850.4	2532	2706	861.6	4.47	81.72	Shittu *et al*. (2008)
Xanthosoma sagittfolium	1941.6	1870.6	71.0	2926.6	1056.0	5.77	61.73	Ejoh *et al*. (2013)
Colocasia esculenta	2407.1	1984.6	422.5	3244.6	1260.0	5.04	61.93	Ejoh *et al*. (2013)
Ipomea batata	496	215	281	192	302	–	–	Hossen *et al*. (2011)
Solanum tuberosum	1087	131	956	742	345	–	–	Hossen *et al*. (2011)

Thermal Properties The behavior of starch granules when subjected to heating helps to explain how easily starchy material can be modified with heat treatment. CF, like cassava starch, has a single thermal event associated with the gelatinization of starch. According to Doporto *et al*. (2012), the onset temperature of gelatinization of cassava starch was about 52°C, whereas that of flour from the same root material was between 67 and 71°C. This indicates that presence of other materials like protein, fat and fiber in CF could have influenced the gelatinization behavior. Grated cassava gave flour with a significantly lower onset temperature than chipped cassava.

Cyanogenic Potential The cyanogenic potential (CNP) is a critical quality factor of CF for both trade and utilization purposes. Although the CNP is reduced by fermentation, flours from bitter varieties of cassava may still contain CNP higher than the acceptable limit of 10 mg/kg by standards. Farmers still cultivate high cyanide cassava varieties due to the perceived higher resistance to pests and diseases. The products are also believed to have superior sensory quality compared to the low cyanide varieties (Chiwona-Karltun *et al.*, 1995). Bradbury (2005) reported a simple wetting method for detoxifying CF having a reasonable amount of linamarase activity. The total cyanide content reduced about 3-fold over 5 h. Addition of exogenous linamarase increased greatly the rate of breakdown of linamarin in the flour. The detoxification process was also found to be pH dependent.

Water Vapor Adsorption Properties The study of water sorption phenomenon allows us to predict the stability and quality during packaging and storage of food products. The plot of equilibrium moisture attainable by a material at constant temperature and varying relative humidity or water activity value is called sorption isotherm. CF is highly hygroscopic due to high water affinity of its starch and fiber. Regardless of whether fermented or not, previous studies on the water vapor adsorption properties of different cassava flours at various practical storage conditions indicated that CF has a type II isotherm curve (Chiste *et al.*, 2012; Doporto *et al.*, 2012; Sanni *et al.*, 1997; Shittu *et al.*, 2015a). The water vapor adsorption isotherm of fufu, pupuru and lafun flours at 27°C is given in Figure 10.1.5. A very wide range of monolayer moisture values have been reported for CF (5–23% dry basis). This might be due to differences in the composition, processing method, and so on. The monolayer moisture contents of

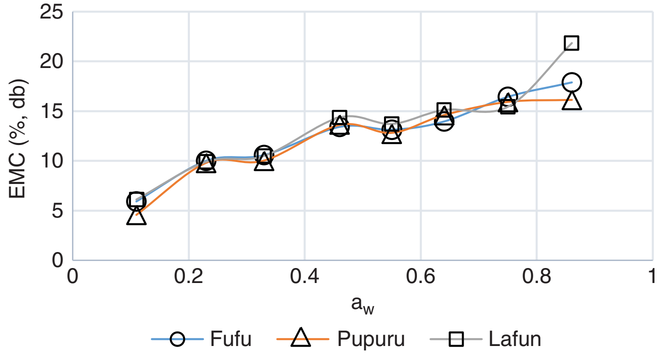

Figure 10.1.5 Water vapor adosprtion isotherm of fufu, pupuru and lafun flours at 27°C (source: Shittu *et al.*, 2015a).

cassava flours from previous studies generally range between 5 and 25% (dry basis). According to Shittu *et al*. (2015a), the difference in the drying method employed in producing lafun, fufu and pupuru did not yield significant differences in the adsorption data at 27 and 35°C.

10.1.2.3 Utilization of Cassava Flour

Fermented CFs has limited applications. Traditionally, they are used to prepare stiff dough (*amala*), often consumed by swallowing whole with some special vegetable soups or stews in many West African countries. However, unfermented or high-quality CF (HQCF) has continued to attract growing food and non-food applications. The bakeries and confectioneries mainly use HQCF as an ingredient in gluten-free or composite baked products. Snack foods such as puff-puff, chin-chin, pies, etc. are made from 100% HQCF or composite cassava-wheat flours. Some chemical industries use HQCF as feed materials in adhesive and glucose syrup manufacture.

Applications of HQCF in Baked Product Manufacture Use of HQCF as a composite material in wheat flour (WF) for bread-making has been explored since the 1970s in Nigeria (Akinrele, 1973). However, substitution of up to 10% wheat flour with CF has gained legislation support in the country since 2004 (Shittu *et al.*, 2007). The major drawback of commercial use of composite flour in baked goods manufacture is the baker's poor technical know-how, inappropriate baking facilities and poor process controls. Most bakeries in Nigeria still use mud-baking ovens with poor baking temperature control. The manual dough preparation used predominantly by the bakers is not efficient to handle the more complex and delicate dough system presented by composite cassava-wheat flour. WF mills with government mandate are now compositing WF with varying levels of HQCF. With this development, the government and private sectors have continued to organize periodic participatory training workshops for bakers to improve their technical skills on composite baked product manufacture. A lot of research and development efforts are still required on the commercial scale to optimize the use of HQCF as a bakery ingredient. Lack of enough domestic capacity to generate the quality and volume of cassava flour needed and poor cassava flour supply chains could also militate against the implementation of the HQCF inclusion policy (Ohimain, 2014).

Studies have shown that gradual quality impairment ensued as the amount of HQCF inclusion is increased for composite bread-making (Eggleston *et al.*, 1993; Khalil *et al.*, 2000). In addition, the cassava root genotype had significant influence on the quality of composite bread (Eggleston *et al.*, 1993; Shittu, 2007; Shittu *et al.*, 2008) (Figure 10.1.6). However, studies correlating HQCF quality with product quality are scarce. Shittu *et al.* (2008) reported that NPK fertilizer application during cultivation of cassava caused significant differences in the cassava flour properties. This further influenced the composite bread quality (Figure 10.1.6). A recent model study has indicated the possibility of predicting the sensory quality of composite cassava-wheat bread from CF properties (Shittu *et al.*, 2015b). Gelation capacity of CF was the most influential flour property affecting the sensory acceptability of composite bread.

Noodle Archaeological facts have shown that consumption of noodles as a food product dates back about 4000 years (Lu *et al.*, 2014). Currently, it is consumed

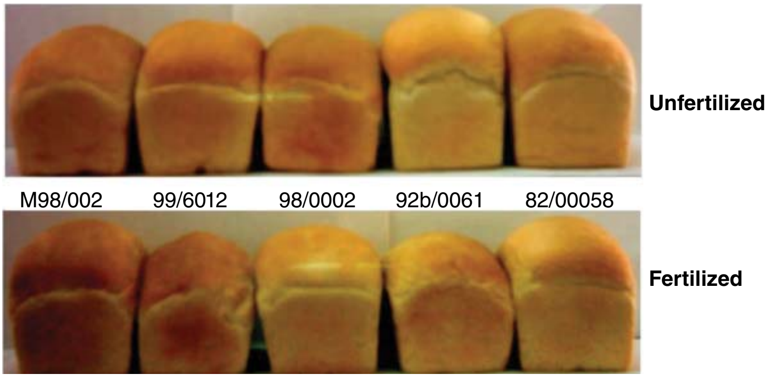

Figure 10.1.6 Composite bread sample by substituting 10% of WF with flours from different cassava genotypes bread by IITA (98/0002, 99/6012, 98/0002, 92b/0061, 82/00058) grown with or without NPK fertilizer (source: Shittu, 2007).

world-wide across all socio-economic strata. The world's noodle market is concentrated in Asian countries, with China being the largest, consuming about 46.2 billion packets in 2013 (WINA, 2014). Noodles were originally made from mung bean flour. Later, wheat flour replaced mung bean flour due to the issue of availability and cost. Nowadays, due to some health and economic reasons, gluten-free flours are now being prospected to partially (Charles *et al.*, 2007) or completely replace wheat flour for noodle manufacture (Nwabueze and Anoruoh, 2009; Purwandari *et al.*, 2014).

Few scientific studies on the use of CF for making noodles have been published. Nwabueze and Anoruoh (2009) studied noodle-making properties of flours from eight cassava mosaic disease-resistant clones. The key sensory attribute responsible for difference in the noodle samples was the texture. Composite flour CF-WF mixture was used to make white noodles (Charles *et al.*, 2007). The noodles had high tensile strength, cutting force and bite force. The texture of the product was improved by adding cassava mucilage. Vijayakumar *et al.* (2010) also reported reduced sensory acceptability of composite flour noodles score with increased CF content. Purwandari *et al.* (2014) studied the effect of water in pre-gelatinized flour as well as proportion of *gathotan* (a fungal fermented flour) to pre-gelatinized flour on noodle quality. Increased proportion of gathotan in the flour mixture caused greater hardness and adhesiveness. The main predictors of overall acceptability for the gathotan noodle samples were the mouth feel and aroma.

Syrups Two processes are followed to produce glucose syrup, namely enzymatic and acid hydrolysis. For the enzymatic approach, the process consists of five stages. The flour is mixed with water into slurry at 105°C. Next is conversion of starch in HQCF to dextrin by addition of α-amylase enzyme. After this, dextrin is hydrolyzed to glucose by adding glucoamylase at 60°C at 1 atm. The glucose syrup is then purified by removing color pigments and ions with the aid of activated carbon and ion exchange, respectively. Additional filtration is required when HQCF is used as a raw material instead of cassava starch. The final process is evaporation to concentrate the syrup. The proportion of glucose, maltose and maltodextrins present in the hydrolysate determines whether it will be called maltodextrin, high maltose syrup or high dextrose glucose syrup. High fructose syrup (HFS) is produced by passing glucose syrup over columns packed with immobilized glucose isomerase.

Thai and Vietnamese glucose syrup production technologies are widely adopted internationally. There is evidence also that small-scale industries in Nigeria and Ghana exist directly by using HQCF for glucose syrup production. Ekha Agro Nigerian Limited is one of the foremost private initiatives in Nigeria that established an ultramodern glucose syrup factory capable of processing 400 tons of fresh cassava root to produce 100 tons of glucose syrup per day at full capacity. It is the second largest glucose syrup factory in Africa.

The development of membrane reactor technologies developed for the improvement of traditional batch processes to overcome the limitations of conventional processes (i.e. product inhibition, cofactor regeneration, biocatalysis in non-conventional media) is a task of growing interest with potential industrial applications. Lopez-Ulibarri and Hall (1997) studied the enzymatic saccharification of CF starch with glucoamylase from *Aspergillus niger* in a hollow-fiber enzymatic membrane reactor (HF-EMR). The saccharification was enhanced by pre-gelatinizing the flour via extrusion.

Adhesives Adhesives mainly used by the paper, textile and packaging industries are originally made from corn starch and imported to many developing economies. In the past two decades, attention has been shifted to using alternative sources of starch such as HQCF. Cassava-based adhesives have the unique advantages of being smooth, clear, fine in texture, non-staining, more viscous, stable and neutral (Gunorubon, 2012). The non-poisonous nature makes it a desirable choice, particularly for many domestic and food applications (Masamba *et al.*, 2003). The major drawback in the use of starch as an adhesive is the stability of the product over time.

The native starch present in HQCF does not yield good adhesive properties. Moreover, the presence of other components such as fiber, fat and protein in HQCF can also reduce its adhesive function (Derkyi *et al.*, 2008). Therefore, when a strong adhesive property is required, attention is shifted to cassava starch. Variables that affect the adhesive properties of starch are formulation, molar mass of starch, starch modification (Emengoa *et al.*, 2002), and so on.

Bioethanol Biodiesel is planned to be a community energy product in certain areas, whereas the bioethanol is recognized as environmentally-friendly energy due to less greenhouse gas (GHG) emission (Nguyen *et al.*, 2007; 2008; Nguyen and Gheewala, 2008).

Co-culture of *Bacillus subtilis* with *Clostridium butylicum* enhanced acetone–butanol–ethanol (ABE) fermentation process. The benefits of using this high amylase producing aerobic Bacillus in a co-culture with anaerobic Clostridium were not only increasing substrate utilization and ABE production, but there was also no requirement to add any costly reducing agent to the medium or flushing with N_2 to ensure anaerobic conditions. This may contribute greatly to developing industrialized ABE production (Tran *et al.*, 2010). Another energy saving approach to make bioethanol directly from cassava chips, by boiling and enzymatically liquefying cassava root, is being taken up in Thailand (Nguyen *et al.*, 2010).

10.1.3 Cassava Starch

Starch is the major food reserve of cassava. It is approximately 21.5% of fresh cassava tuber (IITA, 1990). Like CF, cassava starch (CS) is prepared from either wet mash or dry chips. Starch extraction is easier and economical with wet mash. It also gives consistent and better-quality starch. Particle size from dry milling of chips are highly variable with very fine and coarse materials resulting in constant clogging of the sieve aperture during washing of flour to obtain starch. Also, large quantity of water is necessary to drive the material through the sieve. Since quality is of paramount importance in starch trading, extraction from wet mash is often preferred in commercial starch extraction, because of control over product quality.

10.1.3.1 Cassava Starch Production Technology

While CF is the main commercial product from cassava roots in sub-Saharan Africa, CS is an important export commodity of cassava producing countries of Asia and Latin America. Cassava starch extraction follows a similar pattern with production of CF, except that starch milk is passed through a screen of 150 microns aperture size to separate starch from fibers and other impurities. Typical starch extraction process from cassava roots is shown in Figure 10.1.7.

Washing Cassava starch production is on a larger scale than CF production. Its technology has undergone major transformation from subsistence to commercial production. This is in order to meet global starch demand and compete favorably with starch from other sources such as maize and potato. The technological transformation is more pronounced in Asia and Latin America, especially Thailand and Brazil. After initial quality checks on the roots with the estimation of root starch content through the determination of root apparent density using a Reiman balance, roots are fed through a hopper into mechanized rotary washers fitted with overhead water sprays. Roots are transported through the system by chain conveyors. The tumbling action in the system removes the peel alongside soil and dirt. Soil, sand, peel and other impurities are removed as the roots pass through a rotating cylindrical sieve. Thereafter, peeled roots are moved to a water chamber where these are washed as they are moved by a paddle blade. Capacity of washing in most large CS production factories in Asia is 15–20 t of roots per h (Sriroth *et al.*, 2000).

Cutting and Rasping Rasping is done to enhance starch extraction from cassava roots. The technology is as discussed in Section 11.1.2. Most Asian CS factories rely on locally made motorized raspers. The most commonly-used locally made saw-tooth raspers in Thailand consist of a drum with 144 blades on its surface, with 201 teeth distributed along the length of each blade (Sriroth *et al.*, 2000). This equipment can process 5–6 t of chopped roots per h. Rasping efficiency is measured by the amount of unextracted starch in the pressed pulp, so high starch content in the pulp indicates lower efficiency.

Starch Extraction Particle size and purity are important quality indices for starch. Most large-scale CS processing plants employ two levels of separation using continuous centrifugal starch extractors (coarse and fine) to ensure uniformity and purity of

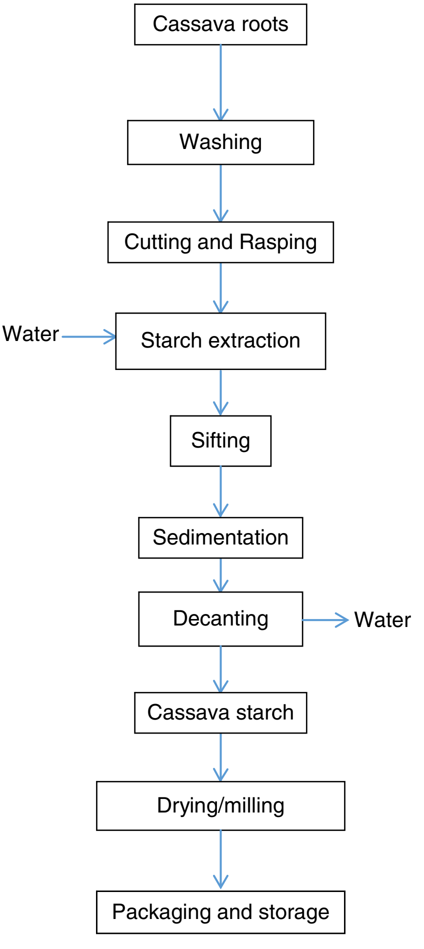

Figure 10.1.7 Starch extraction process from cassava roots.

starch. Some plants incorporate decanters to remove proteins and other impurities. The first stage of extraction is in coarse extractors with centrifugal perforated baskets. Starch is repeatedly extracted from the pulp exiting the extractor with a screen of the same aperture (355–425 μm) as the first pass, until minimal residual starch is achieved. Starch milk from coarse extractor is passed into a fine extractor, which contains a filter cloth and sieve with aperture range from 150–125 μm to remove fine fibers. A higher degree of fineness is achieved by further passing the milk through a sieve of smaller aperture of 140–200 mesh size.

Sedimentation and Decanting The starch milk is then passed into a sedimentation channel for separation of water from the starch. The starch settles while the supernatant liquor flows over a weir and is discharged. The starch is usually allowed to settle in the channel overnight to allow for effective removal of water. Thereafter, the surface of the starch is washed to remove the layers of dirt and other impurities on the surface of the starch mass.

Drying and Milling Drying of CS cake to reduce the moisture content to between 10 and 14% is achieved in the industry through the use of pneumatic conveying flash dryers of the type shown in Figure 10.1.2. The flash dryer is the dryer type of choice in order to prevent modification of starch, which could occur from exposure to high temperatures over long periods. Cassava starch cake fed into flash dryer is blown with hot air and dried to about 12% moisture content within 6 sec (Sriroth *et al.*, 2000). Milling of dried CS is necessary to obtain the right particle sizes required for different applications. Studies on effects of milling on CS are scarce. The moisture content of CS and milling duration used could affect the quality of the resultant starch. Martinez-Bustos *et al.* (2007) studied the effect of moisture content and milling times on the physicochemical properties of CS using a ball mill. Higher moisture contents and longer milling times caused reduction in crystallinity of CS. The starch modification also caused increased water absorption index (WAI) and the water solubility index (WSI) of CS.

Packaging and Storage The choice of CS packaging material is dictated by the structural form of starch and quality requirement. Cassava starch is a highly dusty powder of low moisture content. Prevention of moisture pick-up and leakage are important considerations in the packaging and storage of CS. Dried CS is often packed in polyethylene bags or linen cloth. A double-layered polyethylene bag is often used. A low humid environment is recommended for storage, because of the negative influence of relative humidity on the flow properties of CS (Nduele *et al.*, 1993). Bags of CS are mounted in stores on wooden or plastic pallets, away from concrete surfaces to prevent moisture migration from the surface to the packed starch and destruction of packaging materials by insects and rodents, which could lead to loss of starch and exposure to environmental factors that could affect the quality.

10.1.3.2 Cassava Starch Productivity and Quality

The productivity and quality of CS is affected by three main factors. These are seed gene; environmental factors such as rainfall, soil characteristics and temperature; and farm practices such as irrigation, fertilizer application, intercropping system and weed control. These factors affect starch yield of cassava roots (Pardales and Esquibel, 1996; Santisopasri *et al.*, 2000; Sittibusaya *et al.*, 1993), root starch content (Defloor *et al.*, 1998; Santisopasri *et al.*, 2000), granule size distribution, swelling power (Asaoka *et al.*, 1991; Sriroth *et al.*, 1999a), paste viscosity, pasting temperature (Santisopasri *et al.*, 2000; Sriroth *et al.*, 1999ab), gelatinization temperature (Asaoka *et al.*, 1992), amylose content (Asaoka *et al.*, 1991) and root cyanide content (CIAT, 1990).

Root cyanide content is an important quality factor in CS trade, because of its accumulated effect on the health of consumers. Availability of water during the growth of cassava roots and soil fertility influences the root cyanide content (CIAT, 1990; Santisopasri *et al.*, 2000). Inadequate water during the latter part of the root growth period causes concentration of cyanogenic compounds. Also, depletion of potassium content in the soil increases the cyanide content in the root. Adequate water supply throughout the growth period of cassava root and application of potassium fertilizer is beneficial to the quality of CS, as it leads to decrease in the cyanogenic content of the roots, and stimulates dry matter and starch content (Sriroth *et al.*, 2000).

Table 10.1.5 Standard for cassava starch

Qualifications	Grade		
	1	2	3
Moisture content (% maximum)	13	14	14
Starch (% minimum by polarimetric method)	97.5	96	94
Ash (% maximum)	0.15	0.3	0.5
Acid insoluble ash (% maximum)	0.05	0.10	0.15
Protein (% maximum)	0.3	0.3	0.3
Fiber (cm^3 in 50 g starch before drying)	0.2	0.5	1.0
pH	4.5 to 7	3.5 to 7	3.0 to 7
Residue on 150 μm sieve (% maximum)	1	3	5

Source: Sriroth *et al.* (2000)

Cassava starch, like commercial starch from any other source, is traded based on quality. A documented quality standard and grade of CS found in literature is the one established by the Thailand Ministry of Industry (Table 10.1.5) (Sriroth *et al.*, 2000). The standard and grade would facilitate and promote the trade of CS in international markets. Managing the quality as classified in the standard would improve the competitiveness of CS and encourage its application in the starch-based products.

Global CS Production World starch production was 60 million tons in 2006 (FAO, 2006). Sales from starch and its derivatives stood at $51.2 billion in 2012 and were forecast to increase to $77.4 billion in 2018 through a compounded annual growth rate of 7.1% (BCC Research, 2013). The cassava share of the global starch production was 10% in 2006 (FAO, 2006). Despite being the third largest producer of cassava after Nigeria and Brazil, Thailand has remained a consistent global leader in the production of CS and its derivatives (FAO 2006). Thailand produced 3.5 million tons of CS in 2006, 1.3 million tons (37%) were consumed locally, while 2.5 million tons worth $800 million were exported (Sriroth, 2008).

Utilization of CS The strengths of cassava are mainly in the areas of utilization of its starch and starch-based products. Researchers continue to find new uses for CS, because of the global availability of cassava and ease of extraction of its starch (Essers, 1994). Most importantly, some properties of CS such as bland taste, low gelatinization temperature (71°C), low retrogradation tendency, good stability, high water binding capacity and good adhesive strength (Abraham, 1993; Srirothi *et al.*, 1999b; Jyothi *et al.*, 2005) among others, have been reported to be responsible for its suitability as a base material in various food applications (Falade and Akingbala, 2010). Modification of CS to correct one or more of its shortcomings also gives scope to fabrication of a variety of products for food and non-food applications, thereby adding value and enhancing its versatility (Thranathan, 2005).

Cassava starch is found to be well-adapted to various applications of starch. It has the edge over other starches in bakery because of its expansion property. Based on utilization, cassava starch (like any other starch) is classified into native, modified, hydrolysates and others (Sansavini and Verzoni, 1998). Utilization of cassava starch in food and non-food sectors is presented in Table 10.1.6.

Table 10.1.6 Food and non-food utilization of CS

Sector	Industry	Form of starch	Products
Food	Local consumption	Native	Tapioca
	Food processing industries	Modified/hydrolysates	Bakery and pastry products, noodles, soups, sauces, ice creams, yoghurts, lactic drinks
		Modified	Fat substitutes for dietary products, processed meats, puddings
		hydrolysates	Color enhancer/taste enhancer, canned fruits, juices, soft drinks, marmalades, jams, alternative protein source, seasoning
Non-food sector	Paper and plywood	Modified	Cartons, papers of different quality, plywoods
	Textile	Modified	Fillers, Stiffeners, leather goods
	Pharmaceutical	Modified/hydrolysates	Fillers, excipients, Vitamins C and B_{12}, antibiotics,
	Chemical	Modified/hydrolysates	Glues, cements, paints, oil drilling materials, biodegradable plastics, polyesters, water treatment agents
		Hydrolysates	Soaps, detergents, bleaching agents, insecticides, explosives, cosmetics, industrial alcohols, ethanol, combustibles
	Feed industry	Modified	Feed binder, protein substitutes, carbohydrate substitutes, supplements
	Energy	Hydrolysates/native starch/cassava starch baggase	Biofuels

10.1.3.3 Potential Uses

Tapioca Flakes or Meal Cassava starch is being consumed in its native form at the household level in some West African countries as tapioca. Starch paste is consumed as the main meal or as an accompaniment in dishes. It is also consumed in a partially gelatinized form, also known as tapioca flakes, which is prepared by soaking in water and then cooked in water to form tapioca meal. Sugar and/or milk are added before consumption. It is consumed in many parts of West Africa and widely accepted as a convenience food (Adebowale *et al*., 2006). Oyewole and Obieze (1995) reported some preliminary works on the traditional processing of cassava to tapioca grits. Cassava variety and roasting methods had significant influence on the quality of the product (Adebowale *et al*., 2006) and the sorption isotherms of tapioca grits (Adebowale *et al*., 2007). Adebowale *et al*. (2007) reported that peak and hot paste viscosities were the principal pasting parameters for characterizing tapioca grits from different cassava varieties and roasting methods.

Sour CS Chemical and enzymatic modification of native CS through fermentation is an age-long practice in some African, Latin American and Asian countries (Srinivas, 2007). The products of such modification, which include sour starch (Latin America) (Defloor *et al*., 1995) and *krupuk* (Malaysia and Indonesia) (Howeler and Hershey, 2002), are known to possess specific property of expansion with important applications in bakery (Marcon *et al*., 2009). Sour CS, also known as *polviho azedo* in Brazil and *almindon agrio* in Colombia, is a gluten-free raw material use in production of cheese bread and sour CS *roscas* in Brazil (Marcon *et al*., 2009). The unusual expansion of sour starch during baking is mainly influenced by the interaction of drying and action of lactic acid (Mestres *et al*., 1996; Vatanasuchart *et al*., 2005).

Influence of drying on the degree of expansion was reported by several studies to be dependent on the method of drying; action of ultraviolet radiation in sunlight, which caused significant changes in granule structure of fermented cassava starch such as perforation of the granules; changes in the ratio amylose/amylopectin content; reduction in the polymerization of remaining amylose and amylopectin in the granules, were reported to be responsible for the most significant influence of sun-drying on cassava starch expansion (Demiate *et al*., 2000; Guyot and Mulon-Guyot, 2001; Mestres and Rouau, 1997). A protocol proposed by Marcon *et al*. (2009) showed that maximizing the expansion of sour starch dough would depend on such physico-chemical parameters as degree of polymerization, the number of carboxyl and hydroxyl groups, pH, and granule density among others. Other important factors reported to affect the expansion property of sour CS during baking includes cassava variety, genetic factors, prevailing climatic conditions during the growth and environmental conditions during fermentation (Rickard *et al*., 1991; Tian *et al*., 1991). The resulting organoleptic properties and reduction in acid were mainly driven by lactic acid (Atichokudomchai *et al*., 2004).

Significant improvement has been recorded in the production of sour starch through the adoption of appropriate technologies. Use of locally fabricated equipment for processing and centrifugal separators for starch extraction has contributed significantly to increased sour starch production in the producing countries. However, long fermentation periods of up to 70 days (Mestres *et al*., 1996), and heavy reliance on sun-drying, could be highly unpredictable and inconsistent quality standards have been identified as the major bottlenecks to large-scale commercialization of cassava sour starch production (Marder *et al*., 1996). It is essential to establish standard quality factors and develop effective market penetration strategies to increase utilization of the product and develop affordable technology for efficient waste management to make its production appealing on the large scale.

Controlled fermentation in a covered tank with enough water to ensure anaerobic conditions and inoculation with starter culture were recommended by Brabet *et al*. (1996) for reduced fermentation time. The study also recommended the use of artificial drying apparatus using UV radiation and effective starch moisture control to standardize the drying process and improve the quality of the product, which would not be at the disposition of unpredictable weather condition.

Krupuk *Krupuk* or *keropok* is another important product from Southeast Asia, which also requires expansion properties specific to cassava starch. It is a traditional cracker made from starch and protein source. Processing steps are ingredient mixing, kneading, cooking, cooling, slicing and drying (Taewee, 2011). Reports from several studies show that cassava starch remains the best for the production of krupuk due to its linear expansion capacity, which was reported by Taewee (2011) to be about 80% of the original dough volume and final crispness of the cracker (Mohamed *et al.*, 1989; Saeleaw and Schleining, 2010; Tongdag *et al.*, 2008). Besides the aforementioned factors which affect sour starch, protein source and content also had a significant effect on the final quality of the product. Krupuk are usually named after the added protein source.

Fish and shrimps are the most popular sources of protein for krupuk production. However, fish is often used because the final product is cheaper and affordable and therefore enjoys higher patronage. Inclusion of fish in krupuk enhances the nutrition of the product; however, it has adverse effects on the expansion of the cracker. The higher the fish ratio in the dough formulation, the lower the expansion of the cracker (Cheow *et al.*, 1999; Kyaw *et al.*, 2001).

Major producers of krupuk in Southeast Asia, such as Thailand and Malaysia, have developed quality standards for its trading. However, the production still remains at subsistence or small-scale levels, which makes the enforcement of the standards difficult. Taewee (2011) identified some knowledge gaps that need urgent research to provide information that could assist in standardizing the quality of krupuk and enhance production efficiency.

Chemically Modified Cassava Starch for Food Uses Certain chemicals are added to cassava starch to stabilize its paste viscosity against breakdown during heat processing and agitation. Cassava starch phosphate is utilized in transparent noodles and sauces (Maneepun and Sirirojana, 1990). Addition of acetylated CS to a certain limit was reported to enhance the texture, gloss and flexibility of jelly bean sticks (Maneepun, 1996).

Bioethanol Volatile fossil oil prices, greenhouse effect of fossil fuel emission products and uncertainty of the future of the world's oil reserves, is pushing many countries to look for alternative energy sources. Biomass derived ethanol is the most probable alternatives because of the renewability of the sources. Countries like Thailand and China, who had comparative advantages using CS as ethanol source, formulated policies guiding the production and use of CS fuel ethanol for sustainable energy resources (Hu *et al.*, 2004; Nguyen *et al.*, 2008). Fuel ethanol is used in Thailand as a fuel additive for octane enhancement and also as a blend with gasoline to produce transportation fuels at different ethanol inclusion ratios such as E10, E20 and E85 (figures represent ethanol content). It is an important product from hydrolysis of starch produced through the action of yeast on fermentable sugars. It is a valuable raw material in the pharmaceutical, beverage and chemical industries. As an energy source, it is used as a fuel additive, gasoline enhancer and recently as an alternative fuel source (Ogbonna and Okoli, 2010). Recent interest towards the valorization of cheap and abundant agricultural resources led to research into its production from starch for commercial purposes (Ueda *et al.*, 1981; Verma *et al.*, 2000). More than 90% of global ethanol production is from agricultural products (Rossillo-Calle and Walter, 2006). About 60% of this is from starch crops. Abundant availability of cassava in Asia, Latin America and Africa at very cheap prices compared to corn and other potential competing crops, the high starch content and ease of its extraction, makes cassava the choice raw material for bio-ethanol production (Shanavas *et al.*, 2011). Mussatto *et al.* (2010) reported that CS is the most economical source of ethanol of all starchy sources.

Production of ethanol from CS has witnessed a series of transformations to enhance production efficiency and cost reduction. Cost-effective and productive simultaneous saccharification and fermentation (SSF) processes, in which the combined operation is accomplished at ambient temperatures (≈32°C) (Jaleel *et al*., 1988; Sriroth *et al*., 2010; Verma *et al*., 2000), was designed to overcome the identified shortcomings of the conventional bioethanol production system at industrial levels, which includes economics of production, high energy requirement and environmental concerns due to the large amounts of waste generated. Further improvement to the SSF process was the development of a low-temperature ethanol production process involving highly effective thinning and starch hydrolyzing enzymes that can co-operate with yeast (Shetty *et al*., 2007). Applying Stargen™ 001 to starch slurry (after initial thinning of starch for 30 min) at the ratio of 1:100 (w/w) was reported to yield 558 g ethanol/kg starch, with a high fermentation efficiency of 98.4% within 48.5 h at 30 ± 1°C (Shanavas *et al*., 2011). However, Mussarto *et al*. (2010) identified the high cost of enzymes and left-over residues after fermentation as the major problems of this new development.

To make the production more economical and efficient, a quest is bringing out more innovative methods of obtaining ethanol from CS. Roble *et al*. (2003) developed a system with the use of a circulating loop bioreactor with cells immobilized in loofa (*Luffa cylindrical*) sponge for simultaneous aerobic and anaerobic processes. The result was an improved productivity of 1.17 g/l/h, which is much higher than those reported for other systems. Ultrasound treatment of CS slurry prior to simultaneous liquefaction-saccharification and fermentation led to a significant reduction in fermentation time and enhanced ethanol yield. There was marked improvement in processing efficiency, with reduction in energy consumption (Nitoyavardhana *et al*., 2010). Ogbonna and Okoli (2010) developed a system for the conversion of cassava flour to ethanol through *koji* production (solid state fermentation). The system is a simple and cheap method of producing ethanol in rural settings, since it does not require an electricity supply and addition of enzymes.

Major concerns on the prospects of biomass (including CS) derived fuel ethanol are its energy efficiency and whether it could produce a net energy gain (Dai *et al*., 2006). Different studies had assessed the economic life cycle, net energy gain and societal and environmental impact of bioethanol production from CS (Dai *et al*., 2006; Hu *et al*., 2004; Jansson *et al*., 2009; Nguyen *et al*., 2007; Nguyen and Gheewala, 2008) with a view to providing a framework to guide the policymakers on the viability of the venture. These studies showed that cassava ethanol has a lower net energy, better CO_2 emissions, lower external cost of CO_2 to society and a higher production cost than conventional gasoline. The full benefit of cassava ethanol fuel could only be derived when its advantages are maximized and disadvantages minimized. Using biogas generated from the waste of cassava ethanol production as the main process energy would increase the net energy gains, and reduce the CO_2 emissions with reduced external cost to the society. Also, reduction in the use of fertilizers in plantation stage is encouraged (Papong and Malakul, 2010).

Monosodium Glutamate Monosodium glutamate (MSG) is a popular flavor-enhancing agent and foods additive. Its use started in Asia but is now widespread (Howeler and Hershey, 2002; Jyothi *et al*., 2005). It is produced through the microbial (*Micrococcus glutamicus* or *Brevibacterium* spp.) fermentation of glucose from starch in the presence of urea as a nutrient supplement (Maneepun, 1996). Monosodium glutamate is the major product of cassava starch in Thailand, the global leader in its production. Efforts to residue waste generated during large-scale production of starch from cassava led to attempts to produce L-glutamic acid precursor of MSG from it by submerged fermentation using *Brevibacterium divaritum* (Jyothi *et al*., 2005). Though the amount of glutamic acid obtained from the effort was lower because of the starch content in the waste, the process was reported to be economical considering the low cost of bagasse used as the substrate and the reduction in external cost of CS processing to society.

Lactic Acid and Yeast Studies have reported production of L-lactic acid (Ghofar *et al*., 2005; John *et al*., 2006; Wang *et al*., 2010; Wee *et al*., 2008) and baking quality yeast (Ejiofor *et al*., 1996) from CS hydrolysates through controlled microbial fermentation. Lactic acid is utilized in food, cosmetics, pharmaceuticals, plastics and textile industries (Wang *et al*., 2010). They all reported CS hydrolysate to be a cheap medium for production of these important chemicals.

Paper, Textile and Biopolymers Modification of starch improves its industrial application and enhances its utilization as a substitute for fossil-derived resources. Modified starches are mostly designed for industrial applications, because of the high cost of safety studies needed to certify them by regulatory bodies for food use (Thranathan, 2005). Modified starches find important applications in paper, textile and thermoplastic industries. The paper industry is the main user of modified starch; each tonne of paper requires 55 kg of starch (Tupper, 2000). CS, due to its sterling qualities such as ability to form strong film, clear paste, good water holding capacities and stable viscosity, makes it a good choice for use in paper-making (Cassavabiz, 2005).

Cationic modified starch is widely used in large-scale paper industries to increase tensile fold and bursting strength of the paper (Howard and Jowsey, 1989; Yang *et al*., 2009). Several research efforts have been made to improve the functionality of cationic starch and to improve the economy of its use in the paper industry by devising processes that do not involve costly drying and heating processes, shorten the reaction time and reduce or eliminate the residual reagents in the final product (Fit and Snyber, 1984; Luo and Fu, 2010). Gao *et al*. (2012) attempted to improve on the functional properties of cationic modified CS for paper-making. CS was initially pretreated followed by optimization of the reaction parameters for maximum degree of substitution of cationic starch. The results were the improvement in the pasting stability of starch, increase in the surface area of granules and improved reaction process. Lower breakdown values were reported for starch granules, which indicated higher stability when exposed to heat treatment at higher temperatures and mechanical stirring (Ragaee and Abdel-Aal, 2006).

Starch is utilized in three main areas in the textile industry: sizing, finishing and printing. About 80% of the starch used in textiles is used in sizing. China's textile industry, which is the largest in the world, relies mostly on modified starch from CS obtained locally and through importation from neighboring cassava-producing countries like Thailand and Indonesia (Wang, 2002). Starch modified by graft polymerization is employed in textiles as a sizing agent during weaving and thickener for printing cotton fabric (Hebeish *et al*., 1992; Willet, 2009). Witono *et al.* (2012) optimized graft copolymerization of CS with acrylic acid and observed that the grafting efficiency, temperature, starch concentration and starch to monomer ratio were found to have major influences on the identified parameters.

Biodegradable Plastics Problem of degradation of synthetic polymers by soil microorganisms, which has been causing a serious environmental hazard, led to research for the development of biodegradable plastics (Nakamura *et al.*, 2005). One of the options proposed is the incorporation of natural filler in the polyethylene, which would reduce its mechanical strength and make it porous for subsequent degradation by microorganisms. Several studies have explored the potentials of CS as a filler in synthetic polymers. These include incorporation of CS grafted by radiation with acrylic acid in polyethylene (Kiatkamjornwong *et al.*, 2001), incorporation of native CS in low-density polyethylene and subsequent biodegradation tests in activated sludge (Nakamura *et al.*, 2005) and cassava starch grafted with polystyrene copolymer synthesized using suspension polymerization techniques (Kaewtatip and Tanrattanakul, 2008). They all reported faster degradation and recommended further research into optimization of the processing parameters for subsequent adoption by industry.

Prospective Utilization and Research Starch-albumen powder (SAP) is a composite product of CS and poultry egg white that was developed by Shittu *et al.* (2010a). The functional properties of the product indicated that it has wide potential as an ingredient for food applications in the fast food, baking and confectionery industries. The product is highly hygroscopic and has the typical type II isotherm. The monolayer moisture capacity ranged between 4.9 and 6.8 g/100 g solid. The paste made from the product showed some pseudo-plastic behavior (Shittu *et al.*, 2015c). However, it is yet to have commercial applications.

A potential product that could be of great importance to the energy industry is the hydrogen gas from CS. Cleanliness of hydrogen, high energy density and recyclability is giving its attention as a potential alternative to fossil fuels (Das and Verziroglu, 2001). Su *et al.* (2009) studied the potential of producing hydrogen gas from CS as a substrate and compared the hydrogen yield (HY) and production rate (HPR) using different CS concentrations, pretreatment of CS with either gelatinization or enzymatic hydrolysis, under dark, photo and combination of dark and photo fermentation. The study reported that pretreatment with either gelatinization or enzymatic hydrolysis led to HY and HPR with dramatic reduction in delay time and fermentation time. Combination of dark and photo fermentation recorded a significant increase of HY by about 59.70% from yield in dark fermentation only and increase in energy efficiency to 27.1% from original 18.6% in dark fermentation for starch content of 25 g/l. The report concluded that the combination system has great potential for commercial hydrogen production.

Acetone-butanol-ethanol (ABE) is produced biologically through the fermentation of biomass by *Clostridium* spp. under strict anaerobic condition. This process is important because all products are useful in industry, especially as substitutes for fossil-derived fuels (Jones and Woods, 1986). Butanol is the most valuable of the three, because of its outstanding physical properties such as higher energy content, high boiling points and its compatibility with combustion engines, besides its applications in other industries like food and plastic among others (Jesse *et al.*, 2002; Tran *et al.*, 2010). Tran *et al.* (2010) investigated the potential of producing ABE from CS using a co-culture of *Bacillus subtilis* and *Clostridium botylicum*. The fermentation process was optimized to favor more butanol production. The optimum conditions for enhanced amylase activity and starch utilization was a CS concentration of 40 g/l, yeast extract to NH_4NO_3 ratio of 265/100. The process is economical and has great industrial application, since there is no need for cost anaerobic pretreatment and the substrate is cheap and readily available.

One of the major problems of large-scale CS production is the high amount of waste (bagasse) generated. This bagasse was reported to contain significant amounts of non-extracted residual starch (40–60%) (Pandey *et al*., 2000). Efforts to reduce environmental pollution caused by the waste generated led to research on the prospects of its transformation into industrial by-products. A cardboard-like composite with characteristics similar to the molded fiber packaging from recycled paper was developed by Matsui *et al*. (2004) from cassava bagasse (CB) mixed with Kraft paper. A potentially high-value all-cassava nano-composite packaging material was developed from CB fibers and a thermoplastic CS matrix by Teixeira *et al*. (2009). The incorporation of CB cellulose nanofibrils in the thermoplastic CS matrix resulted in a decrease of the CS hydrophilic character and capacity of water uptake, especially for glycerol plasticized samples.

Products of greater additional values such as mushrooms (Barbosa *et al*., 1995; Beux *et al*., 1995), aromatic compounds like ketone, aldehydes, acid, alcohols and esters (Christen *et al*., 1997), yeast (Ejiofor *et al*., 1996) and organic acids (Shankaranand and Lonsane, 1994) have been developed through biotechnology from CB (Pandey *et al*., 2000). It was also shown to have potential for the removal of heavy metal ions such as Cd(II), Cu(II) and Zn(II) from waste water (Wan Ngah and Hanafiah, 2008).

Cassava has truly assumed the position of an industrial crop on which many nations of the world can base their economies. However, further research and development efforts are still needed to place many of the existing and prospective cassava products from starch and flour in a composition of high competitive advantage among other alternative sources of raw materials for industry.

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