Review

Process-Induced Modifications on Quality Attributes of Cassava (*Manihot esculenta* Crantz) Flour

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Abstract: Cassava flour (CF) is a suitable representative and one of the easiest shelf-stable food products of the edible portion of the highly perishable cassava root (*Manihot esculenta* Crantz). The quality and type of CF are dependent on processing variables. Broadly categorized into fermented and unfermented CF, unfermented CF is white, odorless, and bland, while fermented CF has a sour flavor accompanied by its characteristic odor. The use of fermented CF as a composite is limited because of their off-odors. Modifications in CF processing have given rise to prefixes such as: modified, unmodified, gelatinized, fortified, native, roasted, malted, wet, and dry. Consumed alone, mostly in reconstituted dough form with soups, CF may also serve as a composite in the processing of various flour-based food products. Fermenting with microorganisms such as *Rhizopus oryzae* and *Saccharomyces cerevisiae* results in a significant increase in the protein content and a decrease in the cyanide content of CF. However, there are concerns regarding its safety for consumption. Pre-gelatinized CF has potential for the textural and structural improvement of bakery products. The average particle size of the CF also influences its functional properties and, subsequently, the quality of its products. Cassava flour is best stored at ambient temperature. Standardizing the processing of CF is a challenge because it is mostly processed in artisanal units. Furthermore, each variety of the root best suits a particular application. Therefore, understanding the influence of processing variables on the characteristics of CF may improve the utilization of CF locally and globally.

Keywords: cassava; processing variables; cassava utilization; flour; starch; tuber crops

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a woody perennial shrub with tuberous roots. The genus *Manihot* belongs to the family Euphorbiaceae and is also called *Tapioca, Mandioca, Yucca*, and *Manioc* in different languages [1]. History has it that the crop was domesticated between 7000 and 9000 years ago in South America [2]. It was first imported to Africa by the Portuguese in the eighteenth century, but it is now widely grown with different varieties (Figure 1) in tropical and subtropical regions of Asia, Africa, and Latin America. It currently ranks as the third most important source of carbohydrate in the tropics for human consumption after maize and rice [3]. The plant is drought-resistant, adaptive to harsh climatic conditions, productive in marginal soils, and flexible in planting and harvesting seasons [4]. These admirable agronomic traits make it a reliable and low-cost vegetative crop for food security and other applications [5]. The leaves and roots are the nutritionally valuable parts of the crop, and they make up 6% and 50% of the mature plant, respectively. The enlarged tuberous roots are the main carbohydrate storage locations in cassava, and

they are important not just because they form the bulk weight of the plant but because they are the main part of the plant consumed [6–8].

Utilization of cassava root cuts across various areas: food for humans, feed for livestock, and raw material for various industries, such as manufacturers of textiles, paper, biofuel, confectionary products, and adhesives [9]. In Africa, which is the largest producer of cassava in the world, over 80% of the root produced is used for human consumption as a major staple item [10]. In Latin America, about 40% of cassava produced is used for human consumption, while in Asia, most of the products from cassava are exported [11]. Cassava supplies about 200–500 cal/day for households in developing countries, and different forms of foods can be processed from the root [9,12]. A major setback to the utilization of cassava is that it deteriorates rapidly and cannot be stored for more than a few days after harvesting; therefore, the roots are quickly processed into stable products such as cassava chips and flour [13]. Cassava flour (CF) is a dry powdery product that is directly derived from milling dried cassava chips, after which it may be sieved, or it can also be processed from fresh cassava roots by grating and further subjected to other processing steps [14]. This paper sheds light on the variations in methods of CF processing and how these process-induced changes influence the flour quality.

Figure 1. Photo of different varieties of cassava. Source: [15].

2. Composition and Postharvest Deterioration of Cassava Root

Cassava is primarily a source of carbohydrate, which accounts for about 80–90% of its proximate dry matter composition. The carbohydrate content is approximately 80% starch [16] and little quantities of sucrose (36–46 mg/g), glucose (5–14 mg/g), and maltose (2–19 mg/g) [6,17] on a dry-weight basis. The root consists of the peel and the flesh. The peel comprises 10–20% of the root. The parenchyma, which is the edible portion of the root, comprises approximately 85% of the total root weight, consisting of xylem vessels radially distributed in a matrix of starch-containing cells [18]. Cassava pulp has appreciable quantities of sugars and starches; the quantitative analysis of sugars in cassava pulp of three varieties by Otache et al. [19] showed the following ranges of values amongst the varieties: total sugar (4.02–5.58)%, sucrose (2.60–4.03)%, reducing sugar (0.28–0.34)%, non-reducing sugar (2.74–4.24)%, and starch (27.98–38.34)% on a fresh weight basis.

One major characteristic antinutrient in cassava is hydrogen cyanide (HCN). Hydrogen cyanide is released from the catalytic hydrolysis of two cyanogenic glucosides: linamarin and lotaustralin, occurring when tissues of the root are bruised or crushed [20]. Cassava in its unprocessed form is cyanogenic and highly toxic [21]; therefore, the roots are processed to reduce the cyanide content to safe levels before consumption [22,23].

Cassava also contains antinutrients, such as phytate, nitrate, polyphenols, and oxalate, which can reduce nutrient bioavailability. However, some of these compounds can act as anticarcinogens and antioxidants depending on the amount ingested [24]. Cassava roots contain vitamins A, C, and E and several minerals, such as calcium, magnesium, sodium, potassium, iron, phosphorus, and chloride [25,26]. These bioactive ingredients present in cassava are an indication that the tuberous root may possess some medicinal properties [25].

The fresh roots of harvested cassava cannot be stored because they deteriorate rapidly due to a process known as postharvest physiological deterioration (PPD). The utilization of cassava root is thus limited by rapid PPD, which reduces the shelf life and degrades its quality attributes [12,27]. PPD is a complex biochemical and physiological process that starts with vascular streaking, which is a blue-black coloration later followed by a microbial activity that causes complete spoilage of the root [28]. The rate of PPD sets in immediately so that deterioration and spoilage of roots occur two to three days after harvest. PPD of cassava is a global challenge that hinders the improvement of its value chain [27,29,30]. Studies have been conducted to understand the complex phenomenon responsible for the PPD of cassava storage roots, but still, the problem persists [27,29–35]. To reduce losses due to PPD, the roots are quickly converted to shelf-stable products [13]. Cassava flour is a shelf-stable product of cassava with simple process technology, which can subsequently be used for both industrial and domestic purposes [36,37].

3. Processing and Yield of Cassava Flour

Cassava flour processing has been extensively researched by individual researchers, local and international research institutes such as the International Institute for Tropical Agriculture (IITA), the Technical Centre for Agricultural and Rural Cooperation [14,38–41], and many others. The fundamental steps for processing CF from the root are washing, peeling, chipping, drying, milling, sieving, and packaging. However, in a bid to improve the product quality and meet consumers' preferences, the processing steps may be altered by the addition of other steps such as precooking, fermentation, fortification, and enrichment. Other factors such as temperature, duration, and instrumentation of each step also play important roles in CF processing. These listed processes are highlighted and briefly described in Table 1.

Dziedzoave et al. [41] stated that the yield of CF falls within the range of 13–19%. Eriksson [42] reported the average flour yield of three cultivars as a percentage of fresh cassava weight to be 18.50; the peel and water account for the remaining weight. Falade et al. [43] reported a slightly higher value of 20.67%, and Udoro et al. [44] a much higher range of 36.15–37.03%, which was significantly influenced by peel thickness. Apea-Bah et al. [45] showed that the maturity, moisture, and variety of the root influence the flour yield. The milling and sieving process also influences the recovery of flour. Adesina and Bolaji [46] reported that the pin mill gives a higher flour recovery (approximately 100%) when compared to the hammer, attrition, and mortar mills. The basis (wet or dry) for calculating the percentage yield influences the value obtained [44].

Table 1. Description of cassava flour processing steps.

Processing Type	Processing Steps		References
	Activity and Purpose	Method	
Sorting	To remove spoilt and fibrous roots. Only healthy roots are used.	Manually by visual inspection and discretion.	[39]
Washing	To remove dirt, sand, and soil that adheres to surface of root.	Rinsing with clean water.	[14]
Peeling	To remove outer layer, the stalk, woody tips, and fibrous part of the root.	Manually with sharp knives or other abrasive equipment. Efficient peeling machines are still a work in progress.	[47–50]
Grating	Crushing fresh pulp to form a mash.	Mechanical graters.	[46]
Pressing	Dewatering of fresh mash.	Mash in jute sacks is pressed using dewatering machines such as hydraulic jack and screw press.	[14]
Chipping	The roots are cut into big chunks and then smaller chips (2–3 cm) in length and 1–2 mm thickness.	Manually with knives and chipping machines.	[51,52]
Drying	Reduce moisture content of fresh chips or dewatered mash to about 8–12%.	On surfaces under the sun, cabinet dryers, and hot air oven.	[37,53,54]
Milling	Reducing dried mash or chips to powder.	Pin, hammer, attrition, paddle, or mortar mills.	[46,51,55]
Sieving	To remove large particles or fibers from milled chips to obtain fine flour.	Sieves of varying sizes.	[46,55]
Fermenting	Action of microorganisms to reduce cyanide and develop flavor.	Naturally, soaking or inoculating microbes.	[56–61]
Enriching/fortifying	Fermentation or addition of protein concentrate.	Solid-state fermentation or co-processing with protein-rich materials.	[62,63]
Pre-gelatinising	Heating roots to gelatinize starch content.	Steaming or cooking.	[64–66]
Packaging and storing	Cassava flour is kept till time of use.	In paper bags, plastic bags, or buckets kept on the shelf or refrigerated.	[67,68]

4. Comparison of Cassava Flour and Starch: Physicochemical and Functional Properties

Cassava flour and starch are two similar but different products obtained from the root. They are fine and powdery materials derived from milling and sifting pre-processed cassava root. The processing technology of CF is easier than that of starch. While CF is traditionally obtained by milling the dried root, the starch is extracted as slurry from the wet milling of the root [14]. The flour requires less use of water and a lower amount of byproduct and waste [36]. The components often found in flours include starch, non-starch polysaccharide, sugar, protein, lipid, and inorganic materials [69]. Although starch is the major component of CF, other components may play a significant role in influencing the properties of the flour [69–71]. Due to the very high starch content of CF, it is sometimes referred to as starch. Navia and Villada [39] and Sulistyo et al. [62] used the term CF and cassava starch interchangeably when characterizing the microstructure of cassava flours, probably because the most evident component was starch.

A study conducted on 12 cassava varieties of different textural quality (Figure 2) reveals the properties of cassava starch and its corresponding flour.

The study showed that the pasting temperature of the latter is substantially higher than the former, whereas the reverse is the case for the onset and conclusion temperatures. Moorthy et al. [70] attributed this trend to the presence of fats and sugars, while Niba et al. [71] proposed that the amylase activity and interference of non-starch components may be responsible for this trend. Strong correlations between firmness and alpha-amylase activity, firmness, lipid contents, and fiber, as well as paste viscosity and ash, starch content, and alpha-amylase activity, were reported by Charoenkul et al. [69]. The application of these products are similar, and both may be used in the textile, paper, pharmaceutical, and food industries as a binder, thickener, or glazing agent [14,72]. However, CF is mainly consumed by humans in a reconstituted dough form and is suitable as a composite flour in the production of baked foods such as biscuits and bread.
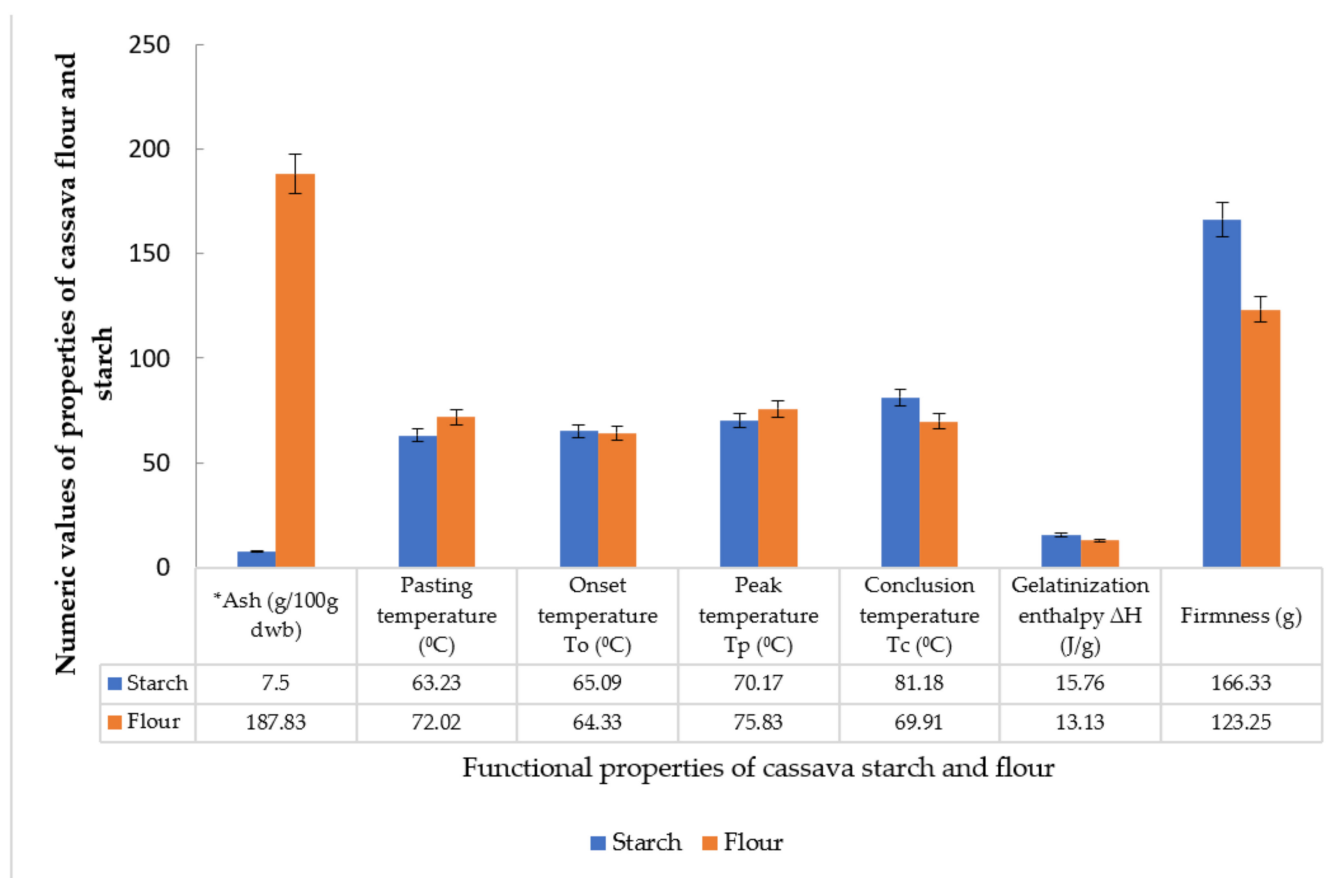
Figure 2. Functional properties of cassava starch and their corresponding flour. All values are average values obtained from 12 varieties of cassava; * actual values in the column were multiplied by 100. Adapted from [69].

5. Classification, Nomenclature, and Properties of Cassava Flours

Cassava flours are broadly categorized into those fermented and unfermented [14]. Unfermented CF is white, odorless, and bland [73], while fermented CF has fermentation as one of its major processing steps, and it has a sour flavor. In most literature [14,41,73,74], unfermented cassava flours are referred to as high-quality CF (HQCF); it appears white, has a low-fat content, is not sour like fermented CF, and does not give an off-odor or taste to food products. The odorless attribute is an advantageous quality of HQCF, which makes it a very suitable composite for various food products because it does not introduce a smell different from that of the original product [73]. HQCF is made within a day of harvesting the root. Mechanized techniques have been developed to reduce the time and energy involved in the process [75]. Local farmers are encouraged to adopt these newly developed modern techniques, which make the process fast and guarantee better product quality [76].

The traditional methods may take too long, and fermentation sets in mostly during dewatering and drying of grated pulps, which adversely affects the functionality of the flour as composite [9]. Most traditional cassava meals are obtained from fermented CF.

These flours are mostly consumed in the reconstituted dough form eaten with soups in most African countries. The fermented flours and their corresponding dough are given various traditional names, such as *Fufu, Lafun, Agbelima, Kivunde, Kokonte, Ugali, and Wikau maombo,* in different regions [10,57,58,63,64,77–84]. From a critical point of view, although the term high-quality may suggest higher nutritional content, it only applies to the starch content. It has been shown in the literature that HQCF has a lower nutritional value but contains a higher amount of high-quality starch than fermented CF [62]. Some authors term unfermented CF as raw [85,86], native [62], and simply dry [66].

There are large variations in CF due to different conditions the root is subjected to during processing [55]. These variations have given rise to various prefixes such as modified, enriched, fortified, pre-gelatinized, roasted, water group, dry group, wet-milled, and dry-milled. Terminologies vary across ethnic groups and regions. For instance, CF milled directly from dried chips may be termed dry group CF [87] or dry-milled [66]. As depicted in Table 2, the proximate composition of the unmodified/native CF is different from the modified flour.

Table 2. Types of cassava flour: physicochemical composition.

Types of Cassava Flour	CHO (%)	Protein (%)	Fat (%)	Ash (%)	Fiber (%)	Moisture (%)	HCN (mg/kg)	Dextrose Equivalent	Total Sugars	Water Activity (a_w)	Reference
Native or unmodified	82.09	1.14	0.93	2.30	2.19	11.49	7.75	2.00			
Modified (enzymatically)	88.80	2.19	0.78	1.44	1.60	5.80	3.88	2.50			[62]
Fortified (fermented with protein hydrosylates)	85.40	11.26	0.75	1.51	1.61	6.44	2.50	3.30			
Pre-gelatinized	64.10–75.31	1.19–1.42	0.38–0.60	1.89–3.28	Nd	8.46–9.76	-	-	-	-	
Dry milled, ungelatinized, and unfermented	72.99–78.76	1.31–1.98	0.48–1.03	2.13–3.36	-	10.57–11.66	-	-	-	-	[66]
Water group	68.32	1.10	1.04	0.75		8.28	-	-	0.42	0.45	
Dry group	76.57	0.52	0.26	0.83		9.17	-	-	1.10	0.53	[87]

6. Microstructure of Cassava Flour

Microstructural analysis of CF using a scanning electron microscope (SEM) reveals that the morphology of different types of CF varied due to fermentation. The degree of hydrolysis by enzymatic modification was evident in the shape and size of the CF granules when compared to the unfermented CF. Observation of the SEM micrographs in Figure 3 shows that the unfermented CF had a smooth surface of starch granules while starch granules of modified CF (MCF) and fermented CF (FCF) were broken with rough and eroded surfaces. The size and amount of granules also decreased. This was attributed to corrosion and enzymatic hydrolysis during processing [62]. The predominant shapes of starch granules in CF are rounded, oval, and truncated, ranging from 9 to 20 μm in size [71].
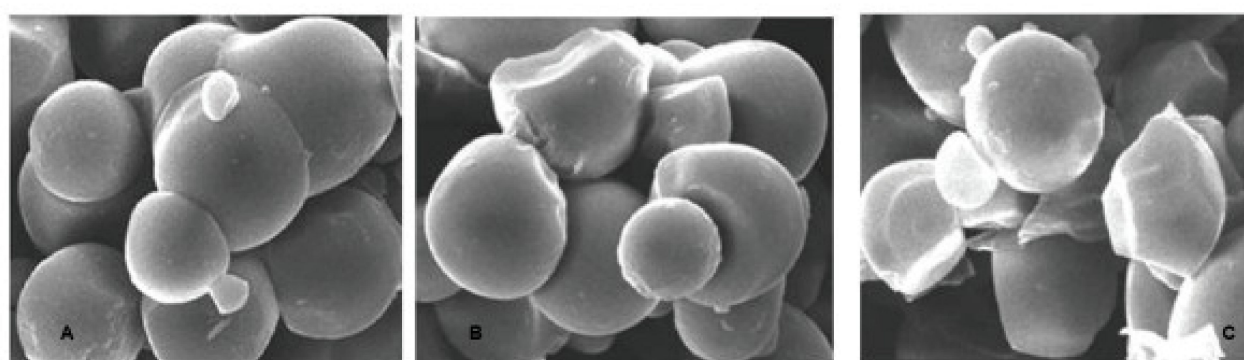

Figure 3. SEM microphotographs of cassava flour: (**A**) Native (unfermented); (**B**) Modified; (**C**) Fermented. Source: [62].

With the aid of High-Resolution Optical Microscopy, micrographs of CF can be obtained (Figure 4). Through an optical microscope coupled with a digital camera and application of toluidine blue dye on samples, fibers and starch granules were distinctly captured [39]. In the micrographs, it was observed that the number of starch granules was greater than the number of fibers in CF.

Figure 4. Micrograph of cassava flour showing longitudinally elongated fiber surrounded by starch granules. Source: [39].

7. Effect of Processing Variables on Cassava Flour

Various literature has shown that variety, maturity, environmental conditions, locations, and postharvest practices affect the properties of cassava [6,45,88,89] and, by way of extension, the quality of its flour.

7.1. Variety of Root

It is recognized that the quality of flour varies with the variety of cassava from which they are processed (Table 3). An extensive study of over 670 cassava varieties grown at the IITA research farm, Nigeria, in 2000 and 2001 was evaluated for genotypic variations in cyanogenic potential and pasting properties [90]. The results showed that there were variations in the cyanide content as well as the genotype x year interactions on the cyanide contents. There were significant ($p < 0.05$) genotypic variations in all the pasting properties except pasting temperature and peak time in 2001. On this basis, the clones were screened and characterized for food, feed, and industrial applications.

The evaluation of the physicochemical and pasting properties of CF processed from 31 different varieties was conducted by Aryee et al. [53]. These varieties were not well adapted because of their poor cooking quality and high cyanogenic potential. Their results showed that starch content ranged from 67.92 to 88.11%. The amylose content of CF varied from 10.9 to 44.3%. The CF had low swelling power values ranging from 5.87 to 13.48. Water binding capacity varied from 113.66 to 201.99%. Gelatinization temperature was in the range of 66.8–70.4 °C, with peak temperatures varying between 73.1 and 84.5 °C. The cyanogenic potential (CNp) ranged from 0.58 to 20.0 mg HCN per 100 g of dry weight. From the data obtained, the authors recommended that these varieties could be used for other purposes such as starch production, glucose, adhesives, fuel alcohol, animal feed, and other industrial uses.

Charoenkul et al. [69] studied the physicochemical characteristics of 12 cassava varieties with low cyanide content from Thailand and reported that all the flours showed wide variation in their properties. Five varieties of cassava, namely, Lakan 1, Sultan 6, Sultan 7, Rajah 2, and Rajah 4, bred and cultivated in the Philippines, were researched by Murayama et al. [66]. The dry and pre-gelatinized flours from these varieties displayed different properties; however, the Lakan 1, Sultan 6, and Sultan 7 varieties were found to be more suitable for pre-gelatinization, mostly due to the greater retention of chemical components. The attributes of CF during storage can be significantly influenced by cultivars; hence, proper selection of cultivars is recommended [67]. The study of Eleazu and

Eleazu [91] indicates that some cassava cultivars of the yellow varieties may have dual utility both for human consumption and for industrial purposes, while the white variety may be confined to domestic use. Pictures of cross-sections of white and yellow varieties are shown in Figure 5. It can be deduced from these studies that although cassava may be used for diverse applications, each variety of cassava best suits a particular application, and depending on the variety and end-use, the right processing condition should be applied.
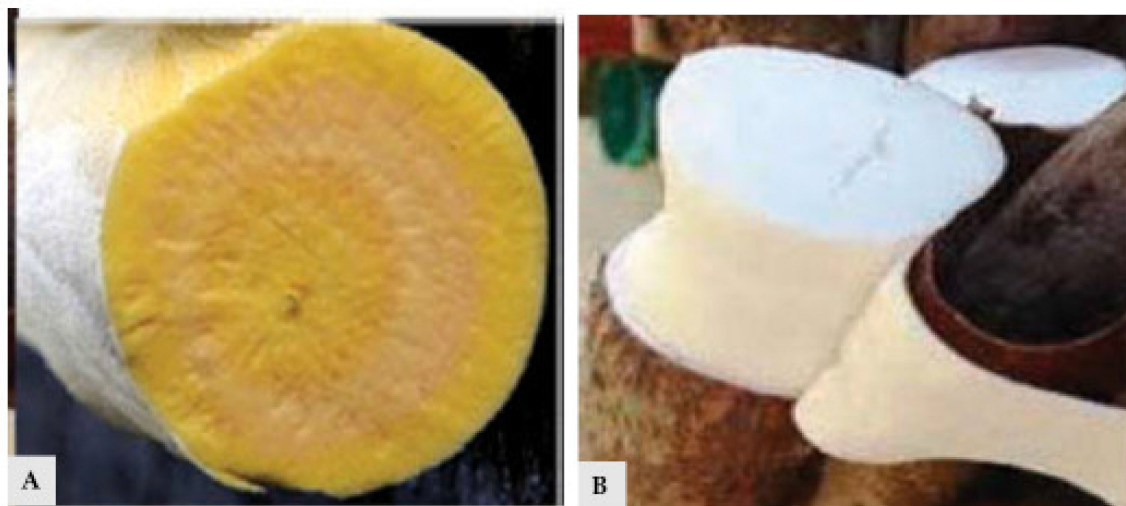

Figure 5. Pictures of cross-section of cassava root. (**A**) Pro-vitamin A cassava variety UMUCASS 36. (**B**) White cassava variety TME 419. Source: [67].

7.2. Pre-Gelatinization

Pre-gelatinization is a process that gives starches the ability to develop viscosity without the need for heat. Pre-gelatinization of CF may be achieved by cooking or steaming the roots before drying and milling. During the application of heat in the presence of water, the starch in the root gelatinizes. An alternative to supplying cassava for industrial use is transforming the roots into precooked CF, which can then be used as a raw material for processing high value-added products such as cassava dough, croquette, fried chips, or snacks. Murayama et al. [66] investigated the effect of pre-gelatinization on the proximate, mineral, and soluble sugar composition, starch, pasting and thermal properties, solubility, swelling power, and particle size distribution of CF. The pre-gelatinized flours showed significantly lower values for viscosity, pasting temperature, and α-amylase activity than their corresponding ungelatinized flours. The use of a differential scanning calorimeter revealed a complete amorphization of the starch contained, and it was deduced that pre-gelatinization causes an increase in the fructose, glucose, amylose content, damaged starch, and mean particle size compared to the corresponding flours that were not gelatinized. From the study, it could be inferred that pre-gelatinization has a great potential for textural and structural improvement by reduction of starch retrogradation in bakery products. Rodriguez-Sandoval et al. [65,93] studied the effects of the cooking (steaming and boiling) method on the retrogradation of starch in flour, and it was reported that CF pre-gelatinized by steaming showed an increase in starch retrogradation, which may be as a result of higher amylose content.

Table 3. Studies on varietal differences in cassava flour (CF).

Number of Varieties	Description of Varieties	Source/Country	Difference in CF Properties Associated with Varieties	References
3	Local varieties	Accra, Ghana	No significant difference in acidity, moisture, and starch content Difference in pasting characteristics, water-binding capacity, and swelling power	[42]
2	White and yellow	National Root Crops Research Institute (NRCRI), Umudike, Nigeria	Significant differences in proximate composition and color attributes; exhibited slightly different hygroscopic behaviors during storage	[67,68]
17	Bitter yellow	State of Bahia, Brazil	Variation in total carotenoid content	[92]
6	New elite yellow and white	NRCRI, Umudike, Nigeria	Higher residual cyanide and quantities of reducing sugar and carotenoid in yellow varieties compared to the white	[91]
31	-	Crop Research Institute (CRI), Ghana	A wide variance in cyanide content, starch content, swelling power, water-binding capacity and gelatinization temperatures	[53]
12	Low cyanide varieties with different cooked textures: mealy, firm and mealy and firm	Rayong Field Crops Research Center, Thailand	Wide variation in pasting characteristics	[69]
11	Different genotypes	IITA, Ibadan, Nigeria	Variation in total dietary fiber and viscosity profile	[71]
5	Varieties developed in the Philippines	Philippines	Slight significant difference in soluble sugar, proximate, and mineral composition	[66]
2	Red and white landraces	Agricultural Research Council, South Africa	Significant difference in cyanide content	[44]

7.3. Fermentation

The positive roles that microorganisms play during fermentation include detoxification, flavor development, biological enrichment, product preservation, and a decrease in cooking time [94]. Fermentation, either naturally or with selective inoculation of microorganisms, has been extensively used to enhance the nutrient potentials of cassava for human consumption [95]. Akindahunsi et al. [56] fermented cassava pulp with *Rhizopus oryzae* (at room temperature for three days), which caused a 97% increase in the protein content of the flour, a 5% decrease in the carbohydrate content, and no considerable increase in the fat, ash and lipid content. The level of antinutrients, tannin, and cyanide, except phytate, was considerably low. The level of phytate increased, and the mechanism of this increase could not be ascertained. It was inferred that this increase might be due to the conversion of some plant metabolite or nutrient content, in the solution, to phytate or phytate-like products. Phytate can chelate divalent cationic minerals such as Ca, Fe, Mg, and Zn, therefore, impairing their bioavailability. However, phytate functions as an antioxidant, inhibiting the formation of free radicals, by sequestering iron [89]. A similar trend was reported by Oboh and Akindahunsi [59] in the use of *Saccharomyces cerevisiae* for fermenting cassava, which increased the protein and fat content of the flour. There was no significant change in the tannin, crude fiber, or ash content of the flour, but there was a significant decrease in the cyanide, carbohydrate, and mineral content. The chelating activity of phytate may be responsible for the decrease in mineral content.

Fermentation with these microorganisms (*R. oryzae* and *S. cerevisiae*) greatly influences the chemical composition of CF positively by increasing the protein level of CF and at the same time reducing the level of some antinutrients, specifically total cyanide. These microorganisms (*R. oryzae* and *S. cerevisiae*) could efficiently improve the nutritional content of CF; however, the knowledge of secretion of some harmful metabolites associated with microbial activities [96] prompted further research by Oboh and Akindahunsi [60] on the nutritional and toxicology of CF fermented with *S. cerevisiae*. They reported high digestibility and no negative hematological effect. However, a significant rise in pyruvate transaminase and serum glutamate oxaloacetate transaminase activities in the serum were observed, which indicates hepatotoxicity and cardiotoxicity. Upon further pathological investigation, the spleen showed some dark red coloration, while the liver had some necrotic lesions [26,60,61].

7.4. Drying and Processing Temperatures

Murayama et al. [66] dried chipped cassava roots in a hot air oven at 40 °C; however, the duration it took to dry was not mentioned. Rodriguez-Sandoval et al. [65] incorpo-

rated resting time after precooking into the stored fresh cassava chips at 5 and −20 °C before drying and milling. The flour stored at −20 °C showed no significant differences in the retrogradation of starch. Rodriguez-Sandoval et al. [93] reported that the temperature during storage was the most important factor affecting the textural properties of cassava dough. Omolola et al. [97] reported that the use of optimum duration and temperature of drying of cassava chips is a key factor in preserving the color and thermal properties of CF. Three traditional processing methods (sun-drying, roasting, and fermentation before sun-drying) were used to produce three types of CF in a study conducted by Eduardo et al. [98]. Their findings inferred that the sun-drying method gave a higher yield than roasting. However, upon use as a composite in bread making, the roasted CF had a significantly higher volume of bread compared with sun-dried or fermented CF.

7.5. Milling and Sieving

In whatever order the process flow takes, milling precedes sieving [98]. Sieving is usually the last step in the flow chart of processing CF before packaging for storage. Milling and sieving are both physical and mechanical processing factors that influence the yield and particle size of CF [46]. However, these processing steps are not given as much research attention as others; hence, there appears to be a dearth of information on the yield, particle size distribution, and average particle size of different types of CFs. The fineness of CF is a function of the efficiency and type of milling machine used [99], and it is also controlled by the attritions on the screen of the mechanical mill. One kg sample of dried cassava chips milled using a pin, hammer, attrition, and mortar mills gave percentage flour recoveries of 96, 87, 75, and 62, respectively [46]. To some extent, the fiber content of cassava makes it difficult to fine mill; thus, its average particle size (228 μm) and most frequently occurring particle size (256 μm) was significantly higher than that of wheat flour [99]. Chisenga et al. [100] reported the average particle sizes of CF in the ranges 250.44–334.34, 103.76–142.42, 90.59–133.19, 63.09–114.75, and 35.56–48.52 μm for sieves 38–425 μm.

Some processors do not sieve after milling, but sieving of the flour gives a better-quality product [74]. According to Sahin and Sumnu [101], the average particle size of various floury foods depends not only on the cell structure but also on the degree of processing that the material undergoes. The use of aperture sized sieves of 180 μm was reported by Murayama et al. [66], while Eduardo et al. [98] reported a lower size of 125 μm, which is within the range (100–150 μm) reported by Lépiz-Aguilar et al. [102]. Aperture sizes of 50 and 550 μm were used to sieve CF in the study of Adesina and Bolaji [46]. In the molding of thermoplastic material from CF, the particle size (ranging from 250 to 600 μm) was included as one of the design factors by Navia and Villada [39]. They established, with the aid of response surface analysis, that the molded material with the highest tensile strength was that with the 600 μm particle size. Sieving is an important step in processing because it determines the particle size, an important physical property, of the flour, which further influences the functional properties of the flour and the subsequent products from them [99]. The particle size of CF can significantly affect its hydrothermal behavior [100].

7.6. Fortification

Due to the high carbohydrate content of CF, fortification is completed to improve the nutritional quality. The addition of flours of legumes and/ or cereal grains to CF is a means of fortification [103]. Co-processing the root with fermented protein hydrolysates not only increased the protein content but also decreased the cyanide content of the fortified CF. There was a significant increase in the viscosity when the level of protein hydrolysates was increased [62]. Another form of fortification is the addition of enzymes such as Termamyl, a thermostable α-amylase, to moistened CF to produce malted CF. The addition of Termamyl to CF resulted in increased hardness of muffins and biscuits baked from it [104].

7.7. Packaging Materials and Storage Conditions

Retaining the quality of CF during storage is a critical factor that directly affects the quality of the flour at end-use. During storage, flours may be packed in low-density polyethylene (LDPE) bags, plastic buckets, sack, jute, and paper bags [105]. The appropriate packaging material, temperature, and relative humidity are critical for the retention of product quality [106]. The use of improper packaging materials could lead to a reduction in the quality and shelf life of flour. CF is best stored at ambient temperature since storage in refrigeration temperature causes an increase in microbial count [67]. During the storage of CF, the whiteness, cyanide, and total carotenoids content decrease in the course of transportation and sales. Opara et al. [68] investigated the effect of plastic buckets, LPDE, and paper bags on the physicochemical and microbial stability of flour of two cassava cultivars under the same temperature and humidity (23 ± 2 °C and 60% relative humidity) for 12 weeks. Total color difference (ΔE) increased with storage time for flours packed in plastic buckets, giving the least color change. Total carotenoid decreased as storage time increased in all packaging materials, but flour packed in plastic had the highest total carotenoid retention. Cassava flour in a paper bag had the lowest microbial count for the total aerobic mesophilic bacteria and fungi.

8. Assessment of Microbial Safety

Cassava flour is majorly produced in artisanal units, which do not adhere to the rules of food safety [107]. The challenge of standardizing small-scale processing is that the processors have various target flour in mind, and the desired end product differs across ethnicity and regions. One constraint in the commercialization of locally produced cassava products is variation in the quality of the products amongst processors and processing batches of the same processor [58,108]. The standard Codex 176–1989; EAS 740:2010 microbiological limits for CF are the total viable count of 5.00 log cfu g^{-1}, *S. aureus* limits 2.00 log cfu g^{-1}, and zero coliform count. However, the result of the studies [58,81,107,109] indicates that some of the microbial limits were exceeded. Although CF is not in its ready-to-eat form, it is worrisome that a very high percentage of the CF samples analyzed were contaminated with very high microbial counts. However, CF samples prepared in the laboratory had a low microbial load compared to samples collected from various processing sites and markets [81]. This implies that although the handling and processing practices of cassava roots expose them to microbial contamination [109], if more hygienic measures are taken, contamination can be avoided, and the safety of the product can be guaranteed.

9. Application of Cassava Flour in Food and Industrial Processes

Postharvest loss of rapidly deteriorating cassava root may be curtailed by processing the tuber into flour. CF can be used as representative of the edible portion of the fresh root because it has the same component as the root, except the moisture [69]. CF is one of the easiest food products from cassava obtained from milling the dried root. Compared to other food products of cassava, such as starch, *gari*, and cassava rice, the processing of CF is less rigorous, which lowers the overall production cost [36]. CF is a major product of cassava; for instance, about 80% of cassava root produced in Brazil is designated for CF [92,107], and almost 70% of cassava root in Mozambique is used in CF production [110]. The agronomic trait of cassava promotes the low cost and all-year-round availability of its flour.

The composite flour program was initiated by FAO in the year 1964, conceived with the primary aim of utilizing locally available raw materials in the production of bakery products in countries that could not meet their wheat requirements [111]. This program must have contributed to the remarkable increase in the research attention given to cassava in the past few decades, especially in African countries. Eriksson [42] stated that the increase in the price of wheat on the global market had promoted interest in utilizing local sources of flour to reduce dependence on wheat and improve the livelihood of local farmers. Cassava flour is now being considered as an alternative to wheat flour. The IITA

and the International Centre for Tropical Agriculture (CIAT) have been at the forefront of enhancing cassava productivity and the development of improved cultivars [8,14,112].

In addition to availability and low cost, CF is gluten-free, and products of this attribute are advantageous, which makes it highly recommended in the diet of celiac patients. Celiac patients struggle with an autoimmune complex that affects the bowel after ingestion of grains or cereals such as wheat and rye that contain gluten [113,114]. Cassava flour has been reported to be a good source (1.93–2.21%) of resistant starch [55], which has the same impact on human health as fiber-enriched foods. The production of short-chain fatty acids due to the fermentation of resistant starches by microorganisms in the colon confers on consumers the benefit of mitigating ailments such as diabetes, cardiovascular diseases, obesity, and osteoporosis [115].

Good quality CF can be processed into various flour-based food products and used as composite flour (Table 4). Different researchers have developed a variety of foods using CF (Table 4), such as bread [116], biscuits [117], noodles [118], and other confectionaries [119], both as composite and the base flour. The use of CF is a convenient alternative to wheat for producing a gluten-free product and developing bio-fortified and fortified foods [40,120]. Cassava flour has the potential to enhance food security, economic development, and consumers' health [121–123].

Table 4. Application of cassava flour (CF) in various flour-based food products.

Flour Composition	Food Product	Level of CF Inclusion (%)	Key Findings	References
Pro-vitamin A CF and wheat flour	Biscuit	10–40	Fat and protein contents of biscuit decreased with increasing proportions of pro-vitamin A CF. Overall acceptability of 10% CF inclusion was same as 100% wheat flour.	[117]
CF with improvers (ascorbic acid, sodium metabisulphite, sorbic acid, and soy flour)	Whole cassava biscuit	100	Slight decrease in mixing time, extrusion time, length, and width of the biscuits.	[124]
CF and soybean flour	Biscuit	50	No significant differences in color, texture, flavor, taste, and overall acceptability of the flour-blend biscuits.	[125,126]
CF (roasted, sun-dried, and fermented), wheat, and maize	Bread	20–40	Type of CF influenced product quality. For example, roasted CF yielded the highest bread volume.	[98]
CF	Noodles	100	CF could serve as a good substitute for wheat flour in noodle production and utilization.	[127]
HQCF and soybean; HQCF and cowpea	Fried snack	50	Soy variant of the snack contained significantly higher protein than the cowpea variant. Product was acceptable to panelist.	[128]
Malted and pre-gelatinized CF with cereal and or legume bran	Muffins and biscuits	70	Pre-gelatinization and malting improved the functionality of CF.	[104]
HQCF, acetylated cassava starch and wheatHQCF, acetylated cassava starch and wheat	Bread	7–32	Increasing component of CF in the blends was found to mask the undesirable influence of acetylated starch on the functional and physical properties of bread.	[129]
CF, wheat, maize, and cowpea	Bread	5–30	Bread with up to 10% CF inclusion was acceptable by sensory panelist.	[99]
CF, wheat, and malted soybean	Bread	10–90	The loaf volume, specific loaf volume, and oven spring reduced appreciably as the substitution with CF increased. It was recommended that CF be substituted for wheat flour up to 30%, using malted soybean flour as an improver.	[130]
CF and wheat	Bread	10–50	CF can serve as a good substitute for wheat flour in bread making.	[131–141]

Table 4. *Cont.*

Flour Composition	Food Product	Level of CF Inclusion (%)	Key Findings	References
CF and wheat	Noodles	50–100	Cassava–wheat composite flour noodles showed promising results, with their acceptability closely following the acceptability of commercial noodles used as control.	[118,142]
Unfermented, dry milled CF and maize	*Tuwo* (a non-fermented maize-based dumpling)	5–30	Cohesiveness indices increased with an increase in the quantity of CF.	[143]
HQCF and soy flour	Ginger-flavoured soy-cassava biscuit	60–100	Sensory evaluation confirmed positive acceptability of the product.	[144]
CF, rice flour, extruded protein concentrate, and pumpkin powder	Gluten-free flatbread and biscuits	Approximately 50	CF could serve as base flour for gluten-free baked products.	[145]
CF, wheat, and soy flour	Biscuit	10–70	No significant difference in overall acceptability between biscuit from the control (100% wheat flour) and the composite flours of up to 40% cassava substitution level.	[146]
CF, Bambara, and wheat	Biscuit	35–90		[147]
CF and cocoa powder	Cocoa-powder-based biscuits	20–100	Use of 100% CF could not form dough for biscuit production. Biscuits with 20% CF were found to be most acceptable.	[148]
CF, pumpkin, and potato	Gluten-free cake	Approximately 35	The flour mix (1:1:1) produced gluten-free cake samples with good nutritional values, cake volume, high freshness, and acceptable sensory properties.	[149]
CF, wheat, and cowpea	Cookies	35–80	Cookies from composite flours were not significantly ($p > 0.05$) different from the control in overall acceptability.	[150]

10. Conclusions

The studies reviewed show that the processing variables, which include variety, fermentation, fortification, pre-gelatinization, sieving, temperature, packaging, and storage conditions, influence the quality of the CF. It can also be deduced that specific varietal selection and manipulation of processing conditions is important to produce different cassava flours suitable for specific purposes. The quest of making CF more suitable for baking may be achieved by objectively controlling the modification process of CF, such as pre-gelatinization, temperature, milling, and sieving to become wheat-like. This is a promising means to advance the utilization of CF globally. The ultimate concern of product safety has to be guaranteed by adhering to safety guidelines during processing as well as proper packaging and storage.

Author Contributions: Conceptualization, E.O.U., T.A.A., and A.I.O.J.; writing—original draft preparation, E.O.U.; writing—review and editing, E.O.U., T.A.A., and A.I.O.J. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are openly available at the referenced numbers.

Conflicts of Interest: The authors declare no conflict of interest.

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