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ORIGINAL PAPER

Assessment of the potential industrial applications of commercial dried cassava products in Nigeria

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Abstract Variations in the functional and pasting properties of four groups of commercial dried cassava product in Nigeria were evaluated in this study, to explore their potential for use as industrial raw materials. In total, 692 products were analyzed using standard analytical methods. The functional and pasting properties of the samples were found to vary significantly ($p < 0.05$). Toasted cassava was found to have the highest water absorption capacity, at 467.42%, and dried cassava the lowest, at 252.57%. Conversely, dried cassava was found to have the highest peak and breakdown viscosities, and toasted cassava the lowest. A significant ($p < 0.01$) positive correlation was found to exist between dispersibility and the swelling power ($r = -0.93$) and solubility index ($r = -0.84$) of the cassava products. Meanwhile, the correlation between dispersibility and the peak ($r = -0.75$) and breakdown ($r = -0.72$) viscosities was positive and significant ($p < 0.05$). Therefore, the authors of this study conclude that user industries such as the food, paper, adhesives, textiles and plywood sectors might require information on the pre-processing of cassava-based feedstock, so as to predetermine the technical usability of such raw materials within their industrial processes.

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Introduction

Cassava (*Manihot esculenta Crantz*) is grown in tropical and sub-tropical parts of the world [1] and serves as the third most important source of calories. It also constitutes about 60% of the daily calorific needs of those living in tropical and Central America [2]. Added to this, cassava plays a major role in alleviating the African food crisis, due to its availability, tolerance of environmentally stressful conditions, and its suitability for use by peasant farmers within their food systems [3, 4]. Cassava has significant potential as a food crop because it is a cheap source of calories and gives high yields per unit area. Nigeria is the largest cassava producer in the world, producing one-third more than Brazil and having almost twice the production capacity of Thailand and Indonesia [5, 6]. Despite its large production output, Nigeria is not an active participant in the international cassava market, because most of its

cassava output is targeted at the domestic food market. As a part of this, Nigeria has not fully exploited the potential use of its cassava within the non-food industrial manufacturing sector.Author: Please check and confirm that the authors and their respective affiliations have been correctly identified and amend if necessary.Authors and their affiliation correctAuthor: Please check and confirm that the added city name is correct in the Affiliation 4.City in affiliation 4 is correct

Significant post-harvest losses of cassava roots occur in Nigeria, as a result of the root's inherent high moisture content, which accelerates microbial deterioration and undesirable biochemical changes [7]. As a result, the roots are processed, to improve their palatability, increase their shelf-life, facilitate transportation and, most importantly, detoxify the roots by removing the inherent cyanogens [8–10]. In Nigeria, cassava roots are used in food products such as *gari*, tapioca, *lafun, fufu*, starch and high-quality cassava flour (HQCF), among others. All these products differ in their functional and pasting characteristics, which are mostly influenced by the processing methods used [11–13].

The major processing features of the cassava root are its functional properties and ability to gelatinize, forming thick pastes suitable for human consumption and for use in many industrial applications. This gelatinization process is a property of the crop's starch granules [14], and such functional properties influence the end-use potential of cassava products. For instance, the granulation characteristics of milled cassava flour affect hydration rates and swelling capacities during processing [15], while color determines cassava products' visual appearance and influences the appeal of the finished products [16]. Meanwhile, the water binding and absorption capacities, swelling power and solubility of cassava have a bearing on the carbohydrate quality, viscosity and gelling ability of the flours and starches produced [17, 18]. In addition, due to some of the undesirable properties of cassava starch, such as a breakdown in the viscosity and cohesiveness of the gelatinized starch paste, very expensive chemical and physical methods are used to improve the functionality of cassava paste for use in industrial applications. These treatments include adding heat, moisture and pressure (to enhance gelatinization temperature and lower viscosity), and also applying ɤ-ray treatments. Oxidation is used to lower the product's viscosity for use in making paper, while esterification is used to either lower, enhance or stabilize viscosity, and to also alter the pasting temperature. Cross-linking is also used to stabilize viscosity [19].

The ongoing expansion of cassava product utilization in Nigeria incorporates the exploitation of such products for multiple uses, taking advantage of the diverse physical and chemical properties conferred to cassava through processing, irrespective of the type of variety or genotype involved. Lately, industrial manufacturers in Nigeria such as paper mills, breweries, feed mills and ethanol plants have been exploring the use of more than one form of cassava product in their industrial

processes, to reduce the impact of current monetary policies that limit access to foreign exchange for raw materials importation. However, the differences seen in the physical properties of cassava products have not previously been investigated in a single study using uniform standard scientific test methods. Therefore the aim of this study is to evaluate and compare the physicochemical properties of different processed cassava products, as a way of assessing and providing science-based evidence for their possible industrial uses beyond food.

Materials and methodology

Survey and collection of commercial, dried cassava products in Nigeria

A survey of dried cassava products traded in Nigeria was first carried out. Using a structured questionnaire, direct interviews were undertaken, to collect cassava processing information from both processors and marketers. Both dried and toasted unfermented and fermented cassava products were collected from the cassava processors and marketers. A total of 43 dried unfermented (15 cassava starches and 28 HQCF samples) and 62 dried fermented cassava products (29 *lafun* and 33 *fufu* flour), plus 40 toasted unfermented (tapioca) and 201 toasted fermented cassava products (144 white and yellow *gari* samples and 57 white and yellow *kpo-kpo gari* samples) was collected. It is important to add that each of the cassava products collected during the survey is a representative of the sampling frame, thus, the unequal sampling size. Samples were kept in polypropylene bags and transported to the laboratory. The samples were separated into the four groups depending on the processing treatments they had been subjected to (Table 1) and were kept at −4 °C until the laboratory analysis was completed.

The processing methods used commercially to make the different dried cassava products are described below.

Dried unfermented product

The dried, unfermented cassava products include cassava starch and high quality cassava flour (HQCF) (Table 1). Cassava starch is produced by first peeling the cassava roots, then washing, grating, pulverizing, wet sieving, sedimenting, decanting, dewatering, drying and milling [11]. This process is similar to that for HQCF except that for HQCF the cassava roots are not pulverized, sieved or allowed to sediment before dewatering [20].

Dried fermented product

Dried, fermented cassava products include *lafun* and *fufu* flour (Table 1). The production of *lafun* involves peeling the cassava roots, then washing them, soaking them in water

Table 1 Processing treatments applied to the processed, dried cassava products

Product group	Moisture removal method used	Predominant root matrix	Local name
Dried-unfermented	Temperature often less than 60 °C for starch; flash dried at 110 °C	Starch extracted through a mechanical process	Starch
		Whole cassava matrix, containing its fiber	HQCF
Dried-fermented	Flash dried at 110 °C	Starch extracted through fermentation	*Fufu*
	Sun dried	Whole cassava matrix, containing its fiber	*Lafun*
Toasted-unfermented	Temperature higher than 200 °C often applied	Starch extracted through a mechanical process	Tapioca
Toasted-fermented	Temperature higher than 200 °C applied	Whole cassava matrix colored with vegetable oil	Yellow fine *gari* Yellow *kpo-kpo gari* (coarse)
		Whole cassava matrix without vegetable oil	White fine *gari* White *kpo-kpo gari* (coarse)

(fermenting), bagging/dewatering, drying and milling the cassava [21]. *Lafun* is also produced by immersing peeled or unpeeled cassava roots in a stream or pool of water, or in an earthenware vessel, then fermenting them until the roots soften, after which the fermented roots are sun dried and milled into flour [21]. The production process for *fufu* flour is similar to that of *lafun*, except that for *fufu* flour, pulverization, and wet sieving comes after fermentation, followed by sedimentation/decantation, bagging/dewatering, granulation and flash drying [22].

Toasted unfermented product

The only cassava product in this group is tapioca (Table 1). The production of tapioca is similar to that of starch, except that toasting of the extracted starch is involved [23]. The toasting carried out here is comparable to that used for *gari*; however, *gari* is a fermented product.

Toasted fermented products

Toasted cassava products include white and yellow *gari* (fine *gari*), and white and yellow kpo-kpo *gari* (coarse *gari*) (Table 1). All the *gari* products are produced by first peeling the cassava roots, then washing, grating, bagging/fermenting, dewatering, granulating, sieving and roasting them [24, 25]. The key difference between the fine and kpo-kpo *gari* products is their particle size distribution; fine *gari* has a particle size of ≤500 μm, while for kpo-kpo *gari* it is >1 mm. The addition of palm oil differentiates white *gari* from yellow *gari*.

Functional properties of dried cassava products

Bulk density

This was determined using the method recommended by AOAC [26]. The sample (7 g) was placed into a 50 ml graduated measuring cylinder. The cylinder was then tapped gently

against the palm of the hand until a constant volume was obtained, and the bulk density (BD) calculated as follows:

$$\% \text{ BD} = \frac{\text{Weight of sample}}{\text{Volume of sample after tapping}} \times 100$$

Water and oil absorption capacity

The water absorption capacity (WAC) and oil absorption capacity (OAC) were determined using the method described by Beuchat [27]. Each 1 g sample was mixed with 10 ml of distilled water for WAC and 10 ml vegetable oil for OAC and blended for 30 s. It was then allowed to stand for 30 min and centrifuged at 3500 rpm for 30 min at room temperature. The supernatant was decanted and the weight of water/oil absorbed by the flour calculated then expressed as WAC/OAC.

Swelling power

This was determined in accordance with the method described by Leach et al. [28], modified for small samples. A sample of 0.1 g was weighed into a weighed test tube, then 10 ml of distilled water was added. The test tube was then heated in a water bath at a temperature of 60 °C for 30 min while being continually shaken. After heating, the test-tube was centrifuged at 2200 rpm for 15 min in order to facilitate the removal of the supernatant, which was then carefully decanted and the weight of the starch paste taken. The swelling power (SWP) was then calculated as:

$$\% \text{ SWP} = \frac{\text{Weight of starch paste}}{\text{Weight of dry starch sample}} \times 100$$

Solubility index

The solubility index (SI) was evaluated by placing l g of the sample into a test tube along with 20 ml of distilled water.

The test tube was then heated in a water bath at a temperature of 60 °C for 30 min. After heating, the test tube was subjected to centrifugation at 2500 rpm for 20 min. 10 ml of the supernatant was then decanted and dried to a constant weight, with the solubility expressed as a percentage by weight of dissolved starch from the heated solution [29]. The SI was calculated as:

$$\% \, SI = \frac{Weight \; of \; solubles}{Weight \; of \; sample} \times 100$$

Least gelation concentration

The method developed by Coffman and Gracia [30] was used in the determination of the Least Gelation Concentration (LGC). Appropriate sample suspensions were added to test tubes each containing 5 ml of distilled water, to make 2–20 % (w/v) suspensions. The test tubes containing these suspensions were heated for 1 h in boiling water (bath) then cooled rapidly under running tap water. The test tubes were further cooled for an hour under the running water, with the LGC determined when the sample from the inverted test tube did not fall or slip.

Dispersibility

This was determined using the method describe by Kulkarni et al. [31]. The samples (10 g each) were added to a 100 ml measuring cylinder along with distilled water, to reach a volume of 100 ml. The mixture was stirred vigorously and allowed to settle for 3 h. The volume of the settled particles was then recorded and subtracted from 100. The difference was then reported as percentage dispersibility.

Pasting properties of dried cassava products

The pasting characteristics of the samples were determined using a Rapid Visco Analyzer (RVA) (Model RVA-4C, Newport Scientific, Warriewood, Australia) interfaced with a personal computer equipped with the Thermocline Software supplied by the same manufacturer [32]. Each sample (3 g of moisture content; less than 12 %) was weighed into a canister and made into a slurry by adding 25 ml of distilled water. This canister (covered with a stirrer) was then inserted into the RVA. The heating and cooling cycles were then programmed as follows. The slurry was held at 50 °C for 1 min, heated to 95 °C within 3 min and then held at 95 °C for 2 min. It was subsequently cooled to 50 °C within 3 min and then held at 50 °C for 2 min, while maintaining a rotation speed of 160 rpm. The viscosity was expressed as rapid viscosity units (RVU). The parameters determined automatically by the instrument were peak viscosity (the

maximum viscosity during pasting), the breakdown viscosity (the difference between the peak viscosity and the minimum viscosity during pasting), the setback viscosity (the difference between the maximum viscosity during cooling and the minimum viscosity during pasting), the final viscosity (the viscosity at the end of the RVA run), the pasting temperature (°C) (the temperature at which there was a sharp increase in the sample suspension's viscosity after the commencement of heating) and the peak time (min) (the time taken for the paste to reach peak viscosity).

Statistical analysis

Analysis of variance (ANOVA), separation of the mean values (using Duncan's Multiple Range Test at $p < 0.05$) and Pearson correlations were calculated using Statistical Package for Social Scientists (SPSS) software (version 21.0).

Results and discussion

Functional properties of the dried cassava products

The functional properties of each of the groups of dried cassava product turned out to be significantly ($p < 0.01$) different (Table 2). Among the groups, the toasted fermented cassava products had the highest WAC (467 %), swelling power (SWP) (632 %) and solubility index (SI) (4 %), but the lowest least gelation concentration (LGC) (14 %) and dispersibility (42 %). The toasted unfermented cassava products had the highest LGC (16 %) and bulk density (BD) (58 %), the dried unfermented cassava products had the highest dispersibility (74 %) but lowest WAC (233 %), and the dried fermented cassava products had the lowest BD (47 %), SWP (325 %) and SI (2 %) ($p < 0.05$) levels (Table 2). This implies that toasting, which leads to partial gelatinization of the cassava root during processing, confers high WAC, SWP and SI properties on cassava. Non-gelatinized cassava products such as starch, HQCF, *lafun* and *fufu* flour maintained low WAC levels. In terms of their practical application within the industry, toasted fermented cassava products might find a use as a stabilizer in frozen products such as ice cream, owing to their high WAC. In addition, the higher SI of these products suggests that more hydrogen-bonding sites could be available for interaction with water molecules, so dissolving in adhesive mixtures and enhance their action [20]. The high SWP of toasted fermented cassava products might make them useful as thickeners and binding agents in food products, and in the non-food sector as adhesives and pastes/glues [24]. This might also be indicative of the toasted fermented cassava products' suitability as disintegrants in the Nigerian pharmaceutical industry [33], so possibly reducing the need to import potato and corn starch [34]. The degree

Table 2 Functional properties of different cassava product groups in Nigeria

	N	WAC (%)	OAC (%)	LGC (%)	BD (%)	Disp. (%)	SWP (%)	SI (%)
Individual product grouping								
Dried unfermented cassava products								
Cassava starch	30	184.23±24.13d	226.49±33.00b	16.46±4.36a	62.66±7.95a	81.77±2.69a	289.55±114.31b	1.28±0.52f
HQCF	56	259.22±65.90c	265.52±57.31a	14.37±6.87bc	46.42±5.50d	69.21±6.97b	583.24±223.48a	2.87±1.32d
Dried fermented cassava products								
Lafun	58	246.14±28.04c	269.00±34.17a	16.49±2.96a	41.10±2.96e	70.28±2.41b	330.87±71.88b	2.67±0.98d
Fufu flour	66	258.24±97.72c	244.24±65.00b	14.35±2.80bc	53.09±7.71c	70.42±5.06b	319.35±81.59b	1.40±0.71f
Toasted unfermented cassava products								
Tapioca	80	343.77±182.80b	187.89±53.43c	16.49±2.97a	58.23±14.54b	48.10±11.70c	584.11±182.13a	2.16±1.69de
Toasted fermented cassava products								
White fine gari	202	450.46±183.19a	224.82±65.40b	13.35±2.50c	56.84±6.50d	43.22±6.50d	634.54±120.96a	4.18±1.15a
Yellow fine gari	86	456.35±231.13a	228.17±127.94b	13.72±2.74bc	56.13±4.80b	43.03±7.02d	630.55±88.12a	3.53±1.26bc
White kpo-kpo gari	94	503.92±143.21a	224.17±44.50b	14.89±2.32b	43.85±7.89de	40.60±8.69de	598.32±84.48a	3.90±1.48ab
Yellow kpo-kpo gari	20	514.70±144.98a	226.05±46.49b	13.59±2.37bc	46.05±7.33e	39.95±8.34e	591.58±59.05a	3.06±1.07cd
Combined product grouping								
Dried unfermented cassava products	86	233.06±65.58c	251.91±53.36a	15.10±6.17b	52.09±10.08b	73.59±8.37a	480.79±237.90c	2.31±1.34b
Dried fermented cassava products	124	252.58±73.81c	255.82±54.11a	15.35±3.05b	47.49±8.46c	70.35±4.03b	324.74±77.11d	2.00±1.07b
Toasted unfermented cassava products	80	343.77±182.80b	187.89±53.43c	16.49±2.97a	58.23±14.54a	48.10±11.70c	584.11±182.13b	2.16±1.69b
Toasted fermented cassava products	402	467.42±185.72a	225.44±78.60b	13.80±2.57c	53.12±8.32b	42.40±7.34d	623.08±105.22a	3.92±1.29a
Total mean		385.5	229.84	14.55	52.57	51.95	547.43	3.17
Interactions								
P product		***	**	***	***	***	***	***
P group		***	***	***	***	***	***	***
P state		***	***	***	***	***	***	***
P market		NS	***	NS	***	NS	NS	***
P processor		NS	NS	NS	NS	NS	*	*
P product×state		***	***	**	***	***	***	***

Means showing different letters in the same column are significantly different (p < 0.05)

N number of samples, *WAC* water absorption capacity, *OAC* oil absorption capacity, *LGC* least gelation concentration, *BD* bulk density, *Disp.* dispersibility, *SWP* swelling power, *SI* solubility index, *NS* not significant (p > 0.05); *p < 0.05; **p < 0.01; ***p < 0.001

of coarseness of starchy foods is measured by its BD [35], implying that dried, fermented cassava product particles are very smooth due to their low BD levels, and so may be used as excipients in pharmaceutical tablets, in paper and in photographic paper powder, as well as cosmetic powders and laundry stiffening agents [36, 37]. Furthermore, the low BD of dried fermented cassava products could provide a smooth texture that exhibits fat mimetic properties [23] when used as a soup thickener or in ice-cream formulations. The higher the dispersibility, the better the starch flour reconstitutes in water [31]. This implies that dried unfermented cassava products with a high level of dispersibility may be suitable for applications in which a lot of starches occupy a small surface area, such as for the adsorptive removal of ions from contaminated water systems [38].

It was observed that fermentation had an increasing effect on WAC, OAC and LGC, but not to a significant degree ($p > 0.05$), and a decreasing effect on the BD, dispersibility, SWP and SI of the dry cassava products. Dried fermented cassava products had the highest ($p > 0.05$) WAC, OAC and LGC values, but lower values for BD ($p < 0.05$), dispersibility ($p < 0.05$), SWP ($p < 0.05$) and SI ($p > 0.05$) when compared with the dried unfermented products. The high WAC values in the fermented products observed here are corroborated by Gregory et al. [39] who reported that microorganisms usually convert carbohydrates to proteins during fermentation. Protein has been reported to be responsible for high WAC and to a lesser extent, starch and cellulose levels at room temperature [39]. Although not tested during the current study, the varieties of cassava used could influence WAC.

Within the dried fermented cassava product groups, *lafun* exhibited the highest OAC (269%), LGC (16%), SWP (331%) and SI (3%) levels, but lower WAC (246%), BD (41%) and dispersibility (70.28%) values when compared with *fufu* flour, and all were significant ($p < 0.05$), except for WAC, dispersibility, and SWP, which were not significant ($p > 0.05$) (Table 2). Within the dried unfermented cassava product group, HQCF produced the highest WAC (259%), OAC (266%), SWP (583%) and SI (3%) values, while cassava starch gave higher values for LGC (16%), BD (63%) and dispersibility (82%) ($p < 0.05$). The WAC, OAC and SWP values for cassava starch shown here are higher than those seen by Ikwegwu et al. [40], but the SI value for the cassava starch reported by Ikwegwu et al. [40] was higher than in this study. In addition, the WAC and OAC values for HQCF reported by Ikwegwu et al. [40] were lower than those seen in this study. The high WAC values as seen for *fufu* flour and HQCF in their respective groups may be attributed to their higher dietary fiber content; as this increases their ability to hold water combined with the loose structure of their starch polymers, while the low values seen in *lafun* and cassava starch might indicate lower dietary

fiber content levels and compactness in their starch molecular structures, as both are more starchy than *fufu* and HQCF [22, 41]. In addition, the high OAC values seen for *lafun* and HQCF are typical for food ingredients that retain flavor in food after having been cooked into a paste. The higher the LGC, the higher the amount of starch needed to form a gel [42] meaning only a small quantity of *fufu* flour and HQCF may be needed to form a gel due to their low LGC, and this means they may be used economically, since less will be required to make food gels. Further, *fufu* flour and cassava starch may be easily reconstituted during food preparation, and might also mix easily with other food ingredients, both due to their high dispersibility [30].

Toasted, fermented cassava products had higher WAC, OAC, SWP and SI values, but lower values for LGC, BD, and dispersibility ($p < 0.05$) when compared with unfermented toasted products. Within the toasted fermented cassava products group, white fine *gari* had the highest BD (57%), dispersibility (43%), SWP (635%) and SI (4%) values, while yellow *kpo-kpo gari* had the lowest values for these parameters, but with higher WAC (515%) levels. The high WAC value shown for yellow *kpo-kpo gari* implies that its starch structure is more loosely bound together than white fine *gari*, which has a low WAC [41]. The OAC was higher in yellow fine *gari* (228%) but lower in white *kpo-kpo gari* (224%) while the LGC value was higher for white *kpo-kpo gari* (15%) than for white fine *gari* (13%). However, most of these parameters were not significant ($p > 0.05$) (Table 2). The high OAC value for the yellow fine *gari* could be attributed to a high affinity for oil shown by *gari*, which already has red palm oil added to [23]. Sanni et al. [24] reported similar values closer to that of the SI and BD of the *gari* products in this study, when researching the properties of *gari* used in Lagos State.

Furthermore, when comparing the fermented and unfermented products based on the methods used to dry them, dried fermented cassava products exhibited high OAC, LGC and dispersibility levels, but low WAC, BD, SWP and SI values when compared to toasted fermented cassava products. This means that fermentation followed by toasting might have a larger increasing effect on the WAC level than fermentation and dry in the sun, or than when using pneumatic dryers. The dried unfermented cassava products revealed high OAC, dispersibility, and SI levels when compared to the toasted unfermented cassava products, which had higher WAC, LGC, BD and SWP levels (Table 2). The effect of starch granular integrity might also be responsible for the significant ($p < 0.05$) negative correlation ($r = -0.68$) that was found to exist between WAC and the breakdown viscosity of the cassava products (Table 4).

This study also found a significant ($p < 0.01$) negative correlation ($r = -0.78$) between LGC and setback viscosity (Table 4). This implies that the higher the LGC, the lower

the setback viscosity and the more stable the cooked gel might be. Thus, dried cassava products with higher LGC in their respective groups may have a greater potential to produce a stable gel when cooked [23]. Furthermore, a significant ($p < 0.01$) positive correlation was found between dispersibility and the swelling power ($p < 0.01$; $r = -0.93$) and solubility index ($r = -0.84$) of the cassava products. Meanwhile, the correlation between dispersibility and the peak ($r = -0.75$) and breakdown ($p < 0.05$; $r = -0.72$) viscosities was positive and significant (Table 4).

Pasting properties of dried cassava products

In view of the fact that all the dried cassava products will be cooked in hot water (except *gari* which may also be eaten having been soaked in cold water) before use in industrial applications, the pasting properties of the products are important in predicting their behavior during and after cooking. The results here reveal that processing methods (products) had a significant effect ($p < 0.001$) on the pasting properties of all the cassava product groupings (Table 3). However, there was a significant difference ($p < 0.05$) found in the peak, trough and setback viscosities of the products in different groups. For breakdown viscosity and peak time, though, there was no significant difference ($p > 0.05$) found between the toasted fermented and unfermented cassava products. Similarly, the dried fermented and unfermented cassava products were found to show no significant difference ($p > 0.05$) in terms of their pasting temperatures. In addition, the dried fermented and toasted fermented cassava products were not significantly different ($p > 0.05$) in their final viscosities (Table 3). Between these two groups, dried unfermented cassava products revealed the highest peak (496 RVU) and breakdown (315 RVU) viscosities, while the dried fermented cassava products had the highest trough (198 RVU) and final (290 RVU) viscosities. Toasted fermented cassava products had the highest setback viscosity (117 RVU) and pasting temperature (78 °C), but the toasted unfermented cassava products displayed the lowest values for all the pasting properties, except for peak time which was high (6 min) (Table 3). The high peak viscosity shown by the dried unfermented cassava products indicates a weak granular structure for its starch when compared to those products with a low peak viscosity [43]. As a result, the dried unfermented cassava products might be inferior to the other cassava products when applied to textiles, due to their high breakdown viscosity. This viscosity may be rapidly lowered on heating under shear, leading to a long and cohesive paste texture, which is something not wanted when applied to textiles [44].

Furthermore, the high final viscosity exhibited by dried fermented cassava products makes them suitable for many food products, such as sauces, soups, and dressings, and also

in the textiles industry and during the paper making process, where high viscosities are required [45]. Meanwhile, the low final viscosity of toasted unfermented cassava products makes them suitable for paper surface applications, those in which a lower viscosity and a good film forming capacity are preferred [45]. The differences observed in setback viscosity levels among the cassava product groups reflect the different thermodynamic behaviors of these products during heating, something which might play an important role in their industrial application. The low setback viscosity of toasted unfermented cassava products results in the formation of a more stable paste viscosity during processing, making them useful in several industries, including textiles. In contrast, the high setback viscosity exhibited by toasted fermented cassava products might limit their use in the food and textile industries [44]. The temperature at which the first detectable viscosity is measured in an amylogram is the pasting temperature, which is a reflection of the swelling of the starch paste and is affected by the starch concentration level [44]. The low pasting temperature of toasted unfermented cassava products suggests they may form pastes more easily than other products, and so may be more suitable for food and non-food industrial processes because of the reduced energy costs incurred. However, the variation seen in pasting temperatures among the different cassava products offers a wide range of options in terms of their utilization in the industrial sector [44].

In this study, and regarding the effect of fermentation on the dried products, dried fermented cassava products tended to show the highest trough, final and setback viscosities, and also peak time levels ($p < 0.05$), but also lower peak and breakdown viscosities ($p < 0.05$), and pasting temperatures ($p > 0.05$), when compared to the unfermented cassava products. Within the dried fermented cassava product group; *fufu* flour had the highest peak time (5 min.), pasting temperature (75 °C), and trough (216 RVU), as well as final (331 RVU) and setback (115 RVU) viscosities when compared to *lafun*, which had higher peak (466 RVU) and breakdown (287 RVU) viscosity values. The peak time and the final and setback viscosities obtained in the *fufu* flour were comparable to those of the rotary and flashed dried *fufu* flour products studied by Sanni et al. [46]. Among the dried unfermented cassava products groups, HQCF had the highest of all the pasting properties ($p < 0.05$) when compared with cassava starch (Table 3).

In addition, the toasted fermented cassava products had higher values for all the pasting properties ($p < 0.05$) (excluding breakdown viscosity), except for peak time, which was lower but not to a significant degree ($p > 0.05$) when compared with the toasted unfermented cassava products. The values obtained for the tapioca's pasting properties were lower than those reported by Adebowale et al. [47], except for peak time and pasting temperature, which were

Table 3 Pasting properties of different cassava product groups in Nigeria

Product group	N	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min.)	Pasting temp. (°C)
Dried unfermented cassava products								
Cassava starch	30	374.93±86.95c	129.67±44.62c	245.26±62.95c	183.44±56.85e	53.77±15.05f	3.90±0.22f	69.06±10.05bc
HQCF	56	561.28±116.78a	208.25±37.96a	353.05±99.59a	292.00±56.12bc	83.89±27.89d	4.18±0.42e	74.24±1.39ab
Dried fermented cassava products								
Lafun	58	465.64±62.50b	178.61±34.55b	287.03±43.68b	243.64±44.50d	66.76±13.43e	4.29±0.18e	69.74±10.25bc
Fufu flour	66	393.52±131.76c	215.70±51.54a	177.83±109.88d	330.59±77.78a	114.89±31.31b	4.90±0.46d	74.57±11.52ab
Toasted unfermented cassava products								
Tapioca	80	89.54±118.61f	60.94±80.85e	28.58±44.73fg	105.21±118.14f	44.27±42.66f	6.05±1.30b	67.61±17.81c
Toasted fermented cassava products								
White fine *gari*	202	241.30±82.86d	185.75±42.91b	55.54±52.69e	318.34±61.93ab	133.02±32.09a	5.65±0.61c	78.36±13.88a
Yellow fine *gari*	86	228.53±86.10d	175.95±43.83b	52.59±55.11ef	278.34±47.40c	104.18±18.06bc	5.80±0.51bc	80.40±15.78a
White *kpo-kpo gari*	94	133.30±61.44e	110.85±54.44cd	22.44±36.61g	210.21±73.63e	101.16±32.11c	6.39±0.91a	76.17±18.83a
Yellow *kpo-kpo gari*	20	129.17±85.58e	104.03±59.40d	25.14±32.14g	188.70±76.14e	84.67±23.51d	6.50±0.56a	69.58±20.25bc
Combined product groupings								
Dried unfermented cassava products	86	496.27±139.23a	180.84±55.05b	315.45±102.18a	254.13±76.48c	73.38±28.09c	4.08±0.38c	72.43±6.47b
Dried fermented cassava products	124	427.26±110.86b	198.35±47.98a	228.91±101.28b	289.92±77.54a	92.38±34.40b	4.61±0.47b	72.31±11.16b
Toasted unfermented cassava products	80	89.53±118.61d	60.94±80.85d	28.58±44.73c	105.21±118.14c	44.27±42.66d	6.05±1.30a	67.61±17.81c
Toasted fermented cassava products	402	207.73±92.21c	162.07±57.37c	45.66±51.01c	278.05±78.90a	116.99±33.56a	5.90±0.74a	77.85±16.02a
Total mean		269.26	159.21	110.05	257.22	98.76	5.46	75
Interactions								
P product		***	***	***	***	***	***	***
P group		***	***	***	***	***	***	***
P state		*	**	*	***	***	NS	***
P market		NS	NS	NS	NS	**	***	***
P processor		NS	NS	NS	NS	NS	NS	NS
P product×state		***	***	***	***	***	***	***

Means with different letters in the same column are significantly different ($p < 0.05$)

N number of samples, *NS* not significant ($p > 0.05$); *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 4 Pearson correlation of the functional and pasting properties of different cassava product groups in Nigeria

	WAC	OAC	LGC	BD	Disp.	SP	SI	Peak viscosity	Trough viscosity	Breakdown viscosity	Final viscosity	Setback viscosity	Peak time	Pasting temperature
WAC	1.00													
OAC	0.06	1.00												
LGC	-0.60*	-0.07	1.00											
BD	0.21	0.55	-0.00	1.00										
Disp	-0.27	0.82**	0.30	0.69*	1.00									
SP	0.12	-0.75**	-0.30	-0.69*	-0.93**	1.00								
SI	-0.23	-0.79**	-0.06	-0.86**	-0.84**	0.88**	1.00							
Peak viscosity	-0.55	0.69*	0.13	0.18	0.75**	-0.56	-0.38	1.00						
Trough viscosity	-0.10	0.73*	-0.38	0.33	0.59	-0.50	-0.45	0.79**	1.00					
Breakdown viscosity	-0.68*	0.59	0.33	0.09	0.72*	-0.51	-0.30	0.96**	0.60	1.00				
Final viscosity	0.17	0.69*	-0.55	0.39	0.49	-0.45	-0.49	0.60	0.96**	0.36	1.00			
Setback viscosity	0.57	0.40	-0.78**	0.32	0.11	-0.18	-0.33	0.11	0.66*	-0.16	0.85**	1.00		
Peak time	0.91**	0.16	-0.37	0.45	-0.03	-0.17	-0.51	-0.48	-0.09	-0.59	0.15	0.49	1.00	
Pasting temperature	0.55	0.70*	-0.46	0.70*	0.48	-0.49	-0.73*	0.26	0.66*	0.04	0.79**	0.80**	0.59	1.00

WAC water absorption capacity, *OAC* oil absorption capacity, *LGC* least gelation concentration, *BD* bulk density, *Disp.* dispersibility, *SP* swelling power, *SI* solubility index

*$p < 0.05$, **$p < 0.01$

higher. This could be attributed to varietal differences and processing methods. Concerning the toasted fermented cassava products, white fine *gari* revealed the highest pasting property levels, except for peak time (5.65 min) and pasting temperature (78 °C), which were higher in the yellow *kpo-kpo* and fine *gari* (Table 3). All the pasting properties of the *gari* reported by Sanni et al. [24] were in the same range as found in this study, except for breakdown viscosity which was lower in this study, and the peak time and pasting temperature levels, which were higher.

Furthermore, when comparing the fermented and unfermented products based on the drying methods used, dried fermented cassava products were found to have a higher peak, trough, breakdown and final viscosities than the toasted fermented cassava products, which instead had higher setback viscosity, peak time and pasting temperature levels. All these properties were significant ($p < 0.05$), except for final viscosity ($p > 0.05$). The pasting properties were significantly ($p < 0.05$) higher in the dried unfermented cassava products, but lower for peak time when compared to those of the toasted unfermented cassava products (Table 3).

The temperature at the onset of any rise in viscosity is referred to as the pasting temperature (PTp) [46]. The PTp is also a measure of the minimum temperature required to cook a given food sample, which has implications for the stability of other components in a formulation and gives an indication of the energy costs incurred during such a process [31]. In this study, all the cassava products were ready, having been cooked at an average temperature of 75 °C, for less than 7 min, so conserving energy during the cooking process. This was because their PTp is below the boiling point of water. The HQCF, *fufu* flour, and white fine *gari* could; therefore, be used in industrial applications such as plywood and paperboard manufacturing due to their high peak viscosity (PV), as this requires a good paste to be produced with moderately high gel strength [48]. Adebowale et al. [49] observed that the higher the breakdown viscosity (BDV) of a starchy material, the lower is its ability to withstand heating and shear stress during cooking. Therefore, tapioca, white *kpo-kpo gari* and *lafun* may withstand heating and shear stress during cooking because of their low BDV levels (Table 3). In this study, it was also observed that for the toasted fermented products, the coarse nature of the *kpo-kpo gari* might have contributed to the low BDV values seen, as there was significant difference ($p < 0.05$) between fine and coarse *kpo-kpo gari* products in terms of their BDV values, even when palm oil was added.

Additionally, a product with a lower final viscosity (FV) has a lower tendency to retrograde, meaning cassava starch, tapioca, yellow *kpo-kpo gari* and *lafun* might retrograde [21, 25, 45]. However, *fufu* flour, white *gari*, and HQCF might retrograde faster after cooking due to their high setback viscosities (SBVs). This might seem obvious, given the significant ($p < 0.01$) negative correlation ($r = -0.78$) between SBV and LGC observed in this study (Table 3). In addition, it was also observed that the PTp value increased as the solubility index fell. This is because a significant ($p < 0.05$) negative correlation exists between PTp and the solubility index ($r = -0.73$) (Table 4). The high dispersibility of HQCF could be responsible for its high PV, due to the fact that in this study a significant ($p < 0.01$) positive correlation ($r = 0.75$) was found to exist between PV and dispersibility (Table 4).

Conclusion

The results of this study show that cassava products can vary significantly in terms of their functional and pasting properties, as a result of the different processing methods used to produce them. In this study, toasted fermented cassava products were found to have the highest water absorption capacities, as well as swelling power and solubility index levels. Dried unfermented cassava products; meanwhile, had the lowest water absorption capacities, and dried fermented cassava products had the lowest swelling power and solubility index levels. Dried unfermented cassava products exhibited a high peak and breakdown viscosities, while dried fermented cassava products revealed high trough and final viscosities. Toasted unfermented cassava products had the highest setback viscosity and pasting temperature levels, but the toasted fermented cassava products had the lowest of all the pasting property values, except for peak time. Therefore, manufacturing industries intending to use cassava products, such as those in the food, paper, adhesives, textiles and plywood making sectors, should seek information on the pre-processing of cassava-based feedstock, so as to predetermine the technical usability of the raw materials applied in their industrial processes.

Compliance with ethical standards

Conflict of interest No conflict of interest is reported.

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