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ORIGINAL ARTICLE

Adoption of improved cassava varieties by processors is linked to processing characteristics and products biophysical attributes

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Abstract
Evidence from community cassava processors on product quality traits that influence variety adoption was combined with laboratory methods to identify potential predictors of quality traits of new varieties. The study revealed that high product yield, high starch content, high solubility index (SI), high peak viscosity (PV), low setback viscosity, and delayed root color change (delayed postharvest physiological deterioration) are possible laboratory indicators that could be used as proxies for predicting product quality and variety adoption decisions of cassava processors. Fufu exhibited higher swelling power, SI, and PV than gari from the same varieties. Processors preferred quality characteristics are difficult to measure for several hundreds of new germplasms in the early stages of the breeding cycle. The information presented may be helpful during the breeding of new, improved varieties by using the physical and chemical properties of the roots that predict processors' preferred quality traits.

Practical applications
The study identified laboratory parameters that could be used as predictors of processors-preferred traits in new breeding lines with a higher possibility of adoption by processors to make commercial success products.

1 | INTRODUCTION

The impact of any agricultural technology depends on the extent and scale of its adoption (Ayinde et al., 2017; Wossen et al., 2018). Also, the rate of adoption of new technology by farmers is related to the agricultural procedures and risk involved, the profitability, the financial capacity, and the socioeconomic status of the farmers (Ayedun et al., 2020). Farmers adopt cassava varieties to meet their income, food security, culinary and agronomic needs, and the desire to preserve their cultural identity by retaining the local varieties while adopting the new varieties (Awoyale et al., 2020). There is considerable evidence showing that adoption behavior is affected by demographic variables, technology characteristics, information sources, knowledge, awareness, attitude, and group influence (Ayedun et al., 2020; Ayinde et al., 2017). In addition, other factors such as marital status and years of farming experience of the farmers, availability of improved planting materials within the village, and information through radio and news influence farmers' decisions on adopting any improved variety (Udensi et al., 2011). Afolami et al. (2015) reported that the dis-adoption of improved varieties might result from a lack of planting materials of improved varieties, firm belief about local varieties and their trust in what they used.

Cassava varieties are divided into two; bitter varieties, which have a relatively high cyanogenic content and can be toxic if not properly processed before consumption, and the sweet varieties, which usually have very low cyanogenic content and may be consumed raw, boiled or roasted (Nweke, 2004). Cassava farmers may prefer bitter types of varieties because they are less prone to being dug up by rodents, monkeys or wild pigs (Pircher et al., 2019). The same farmers may also prefer the sweet varieties for quick boiling to feed workers in south-west Nigeria (Teeken et al., 2018) or for planting close to the homestead where goats can be poisoned by eating the bitter types and wild animals are not a threat. However, Thiele et al. (2021) confirmed that insufficient priority given to consumer-preferred traits by breeding programs contributes to the limited uptake of improved varieties and their low varietal turnover. Also, Awoyale et al. (2020) reported that varietal differences play essential roles in producing different value-added cassava products and significantly affect the physicochemical, functional, and quality characteristics of the products processed such as fufu, gari, pellets, and high-quality cassava flour (Awoyale et al., 2020).

Gari, a roasted, fermented cassava grit, is the most popular product consumed in West Africa and an important food product in the diets of millions of people in developing countries (Awoyale et al., 2021). Gari could be eaten directly (dry); eaten with water, sugar, groundnuts, and/or cashew nuts added; cooked in boiled water into *eba* dough, or sprinkled on cooked beans (Adinsi et al., 2019). Both cassava varieties and variations in the processing of gari contribute to the differences in consumer preferences (Bechoff et al., 2018). Noticeable variability is observed among traditional gari types, depending on processes used, which can confer different sensory properties (color, particle size, dryness, and sourness) on the product. The primary sensory attributes of uncooked gari are appearance, color, taste, acidity, sweetness, aroma, and crispiness (Laya et al., 2018; Owuamanam et al., 2011; Udoro et al., 2014). The primary sensory attributes of eba, which is made by reconstituting gari in boiled water, are appearance, color, texture, taste, aroma, mouldability and stretchability (Eje et al., 2015; Olaleye et al., 2018; Oluwamukomi, 2015).

Fufu is a traditional fermented food product in southern, western, and eastern Nigeria and some West African countries. Fufu is ranked second after gari in Nigeria in terms of consumption volume. It is usually consumed as cooked *fufu* dough with soup (Chijioke et al., 2021). Sour taste, intense aroma, white color, and smooth texture are the quality characteristics and determinants of fufu acceptance (Bamidele et al., 2015). The variations in processing methods and differences in physicochemical properties of cassava varieties influence the texture and organoleptic properties of the cooked fufu (Chijioke et al., 2021). A study by Awoyale et al. (2020) showed that consumer-preferred quality traits are the eventual determinants of the adoption decision of commercialized cassava farmers. Furthermore, Ayetigbo et al. (2018) observed that a conservative attitude of farmers particularly impairs the adoption of the biofortified cassava varieties, unwillingness to try new methods or crop varieties, poor understanding of the advantages of biofortified varieties compared to the white-flesh cassava varieties, and misconception of biofortified varieties as genetically modified. To resolve these challenges, Mbanjo et al. (2021) suggested an increased emphasis on the use of biochemical parameters as indices for determining quality traits because quality traits influence varietal adoption and product utilization. Chijioke et al. (2021) reported that ease of forming a dough, thickness, and drawing-ability of fermented wet fufu mash during cooking are the quality preferences for processed cassava products, and the attributes preferred by both men and women. The authors added that smoothness and ease of swallowing were preferred attributes for cooked *fufu* while being sticky, and intense aroma were less preferred in cooked *fufu*. However, testing for such parameters during the early cassava breeding cycle poses some challenges due to many clones often screened.

Knowledge of laboratory-based quick testing methods for biochemical indicators of quality traits can help predict varieties with a high possibility of adoption by processors for making specific processed products. Such knowledge during breeding will be helpful to select and target different varieties to specific market segments or end-users, such as rural farm households and commercially oriented processors. As the first step, identifying such biochemical indicators using the currently adopted or dis-adopted cassava varieties will help understand the rationale behind cassava processors' variety adoption decisions. This study aimed to understand how the adoption of improved cassava varieties by processors is linked to processing characteristics and products biophysical attributes by evaluating the functional, pasting, and chemical properties of two most popular cassava products (gari and fufu).

2 | MATERIALS AND METHODS

2.1 | Scoping study

A scoping study was conducted through interviews with farmers and processors in communities across three randomly selected Local Government Areas (LGAs) (Afijio, Akinyele, and Ido LGAs) of Oyo State, Western Nigeria. The Southwest of Nigeria was reported to have the highest adoption rate of improved varieties (79%) in Nigeria (Wossen et al., 2017). The selected LGAs are known for the high-intensity processing of cassava into traditional products such as gari and fufu. Consumers further cook gari to make *eba*, while wet fufu (henceforth written as fufu) is similarly cooked to make *fufu* dough (henceforth written as cooked *fufu*) for the table. The local processors purchase large quantities of roots from over 450 farmers from Oyo and the nearby states of Osun and Ogun. A minimum of 20 community-based cassava processing centers (CPCs) exists in each of the selected LGA. An average of 150 processors operates in each of the processing centers daily. They hire an average of 1500 persons for processing activities such as transportation, loading-and-offloading of roots, peeling, washing, fermenting, dewatering, drying, roasting, milling, packaging, and sale of processed products. The activities of the CPCs offer marketing opportunities for fresh roots to farmers in the three states. Ten CPCs were randomly selected for the study. Ten randomly selected farmers and processors per community were interviewed. Information collected included varieties liked and disliked for gari

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and fufu production, including the processing characteristics and consumer traits.

The varietal information received from the interviewees was used to select varieties for the subsequent processing experiment.

2.2 | Materials

Based on the scoping study, cassava varieties were selected for processing into gari and fufu. Four varieties classified by the processors as local: Kabiesi, Okoyawo (Oko Iyawo), Paroba, and Sharp; and four varieties classified by the processors as improved: ITA, ITA1, TME419, and TMS980002. The varieties were purchased from farmers from Akinyele LGA. They have had interactions with cassava breeders at the International Institute of Tropical Agriculture (IITA) (Akinyele LGA, Ibadan) over time by being either previously involved in cassava variety testing experiments or have received planting materials from IITA. The selected local and improved cassava varieties were confirmed on the farmers' farms by an expert before selecting them for the experiments. All the varieties were available and used for commercial gari or fufu production in this location. The cassava roots of the different varieties were harvested during the rainy season at 12 months after planting (MAP). The cassava roots were then processed into gari and fufu and evaluated for product yield and functional, pasting, and chemical properties.

2.3 | Methods

2.3.1 | Production of gari

The gari samples were produced using the method described by Awoyale (2018) with some modifications. About 20 kg of freshly harvested roots from each variety were used. The roots were peeled with a stainless-steel knife to remove the outer brown skin and thick inner cream layer, manually washed using a sponge to remove stains and dirt, then grated using a mechanical grater, collected into woven polyethene sacks using a stainless-steel scoop, and fermented for five days at room temperature (29 ± 2°C). The fermented mash was placed on a manually operated pressing machine for dewatering. The dewatered cake was pulverized with a stainless-steel pulverizer and roasted manually in a stainless-steel roasting pan (Figure 1). All the gari processing machines were manufactured by Niji Lucas Limited, Lagos, Nigeria. The gari was allowed to cool and then packaged in woven polyethylene bags before laboratory analyses.

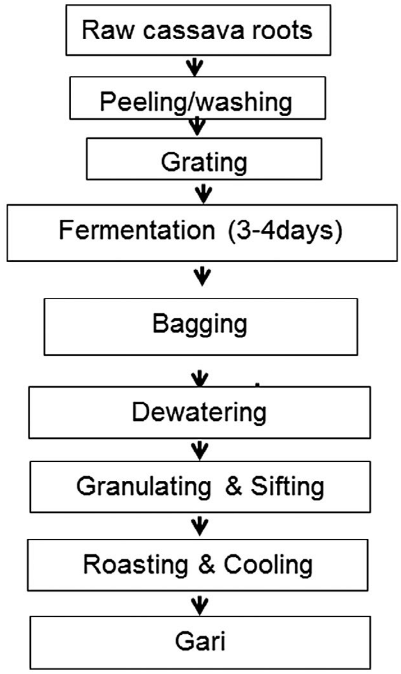

FIGURE 1 Flowchart to produce gari (Awoyale et al., 2020)

2.3.2 | Production of fufu

The local method of fufu production was used, as described by Sanni and Akingbala (2000). The roots (30 kg from each variety) were peeled with a stainless-steel knife, washed with potable water using a sponge to remove the dirt, and soaked in potable water for four days in a plastic fermenting drum. The fermented roots were sieved through a muslin cloth, and the fufu slurry was allowed to sediment. The slurry was collected by descanting the surface water, packed in woven polyethylene sacks, and dewatered using a pressing machine. The cake was pulverized with a stainless-steel pulverizer and dried in a cabinet dryer at 60°C for 24 hr (Figure 2). The dried product was milled using a hammer mill, cooled, and packaged in polyethylene bags before laboratory analyses. All the fufu processing machines were manufactured by Niji Lucas Limited, Lagos, Nigeria.

2.3.3 | Product yield

The yields of the gari and fufu were determined by dividing the final mass of dried fufu or gari by the initial mass of the fresh, unpeeled roots multiplied by 100 (% product yield on a wet basis) (Awoyale et al., 2020).

2.3.4 | Functional properties of cassava products

Bulk density

About 7 g of the sample was weighed using an Ohaus weighing balance (PA214, Switzerland) into a 50 ml graduated measuring cylinder (AOAC, 2000). The cylinder was tapped gently by hand palm until a constant volume was obtained, and the Bulk density (BD) was calculated.

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

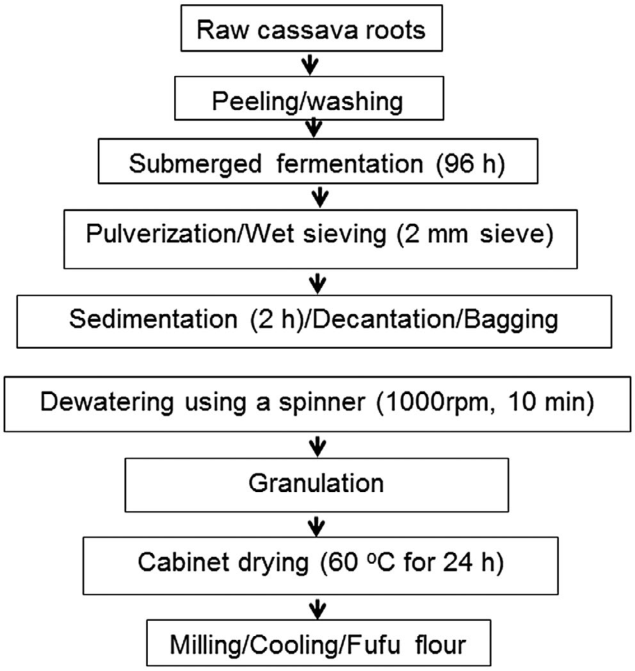

FIGURE 2 Flowchart to produce fufu flour (Sanni & Akingbala, 2000)

Water absorption capacities

The water absorption capacity (WAC) of the samples was determined using the method described by Beuchat (1977). The samples (1 g) were mixed with 10 ml of distilled water and blended for 30 s to determine the WAC. The samples were allowed to stand for 30 min and centrifuged (Gallenkamp model 90-1, England) at 3,500 rpm for 30 min at room temperature. The supernatant was decanted, and the weight of water absorbed by the sample was calculated and expressed as the respective WAC.

Swelling power

Swelling power was determined following the method described by Leach et al. (1956) with modification for small samples. A sample of 0.1 g was weighed into a weighed test tube; 10 ml of distilled water was added and heated in a water bath (Thelco, model 83, USA) at a temperature of 60°C for 30 min with continual shaking during the heating period. In the end, the test tube was centrifuged (Gallenkamp model 90-1, England) at 2,200 rpm for 15 min to facilitate the removal of the supernatant. The supernatant was carefully decanted, and the weight of the starch paste was taken. The swelling power was then calculated.

$$\text{Swelling power} = \frac{\text{Weight of starch paste}}{\text{Weight of the dry starch sample}} \times 100.$$

Solubility index

The samples' solubility index (SI) was evaluated by weighing (using Ohaus PA214, Switzerland weighing balance) l g into a test tube with the addition of 20 ml of distilled water. This mixture was subjected to heating in a water bath at 60°C for 30 min. At the end of heating, it was centrifuged at 1,600 rpm for 10 min, after which 10 ml of the supernatant was poured out and dried to constant weight, and the SI was reported as the percentage by weight of dissolved starch from a heated solution (Kainuma et al., 1967).

$$\text{SI} = \frac{\text{Weight of solubles}}{\text{Weight of sample}} \times 100.$$

Least gelation concentration

The method of Coffman and Garcia (1977) was used in the determination of the Least gelation concentration (LGC). Appropriate sample suspensions were weighed (using Ohaus PA214, Switzerland weighing balance) into 5 ml of distilled water to make 2%–20% (w/v) suspensions. The test tubes containing these suspensions were heated for 1 hr in boiling water (bath) followed by rapid cooling under a running tap. The samples were further cooled for an hour under running water, and the LGC was determined as the concentration when the sample did not slip or fall from the inverted test tube.

Dispersibility

The *s*amples (10 g) were weighed using an Ohaus weighing balance (PA214, Switzerland) into a 100 ml measuring cylinder, and distilled water was added to reach a volume of 100 ml. The mixture was stirred briskly and allowed to settle for 3 hr. The volume of settled particles was observed on the measuring cylinder, recorded, and subtracted from 100. The difference was then reported as the percentage dispersibility (Kulkarni et al., 1991).

2.3.5 | Pasting properties

The pasting properties of the samples were determined using a Rapid Visco Analyzer (RVA) (Model RVA-4C, Newport Scientific, Warriewood, Australia) interfaced with a computer equipped with the Thermocline Software supplied by the same manufacturer (Newport Scientific, 1998). Samples, each 3 g, were weighed using a weighing balance (Ohaus PA214, Switzerland) into a canister and made into slurry by adding 25 ml of distilled water. This canister (covered with a stirrer) was inserted into the RVA. The heating and cooling cycles were then programmed: 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 the rotation speed (160 rpm) was maintained. The viscosity was expressed as Rapid Viscosity Units (RVU). The instrument automatically records the following parameters: peak viscosity (maximum viscosity during pasting), breakdown viscosity (the difference between peak viscosity and minimum viscosity during pasting), setback viscosity (the difference between maximum viscosity during cooling and minimum viscosity during pasting), final viscosity (viscosity at the end of the RVA run), pasting temperature (the temperature at which there is a sharp

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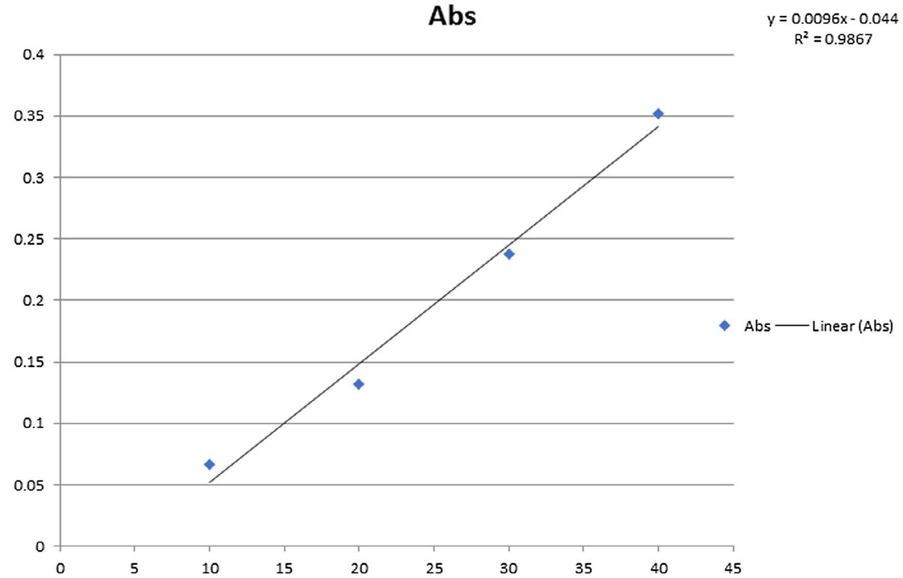

FIGURE 3 Standard glucose curve showing the regression coefficient and R^2

increase in the viscosity of the flour suspension after the commencement of heating) and peak time (the time taken for the paste to reach peak viscosity).

2.3.6 | Chemical composition

Moisture content

About 3 g of the sample was weighed using a weighing balance (Ohaus PA214, Switzerland) into a pre-weighed, clean, and dried dish and placed in a well-ventilated oven (draft air Fisher Scientific IsotempR Oven model 655F) maintained at 103 ± 2°C for 24 hr. After drying, the sample was collected, placed in a desiccator to cool to room temperature, and weighed. The loss in weight was recorded as the moisture content (AOAC, 2000).

$$\text{Percentage moisture content} = \left(\frac{M_1 - M_2}{M_1 - M_0}\right) \times 100$$

where M_o = Weight in g of dish; M_1 = Weight in g of dish and sample before drying; M_2 = Weight in g of dish and sample after drying; M_1–M_o = Weight of sample prepared for drying.

Ash content

The sample (3 g) was weighed using a weighing balance (Ohaus PA214, Switzerland) into a well-labelled crucible and placed in the furnace (VULCANTM furnace model 3-1750) to burn off moisture and all organic constituents at 600°C for 5 hr. After ashing, the sample was collected, placed in a desiccator to cool to room temperature, and weighed. The residue weight after incineration was recorded as the ash content (AOAC, 2000).

$$\text{Percentage ash content} = \left(\frac{W_3 - W_1}{W_2}\right) \times 100$$

W3 = Weight of crucible + ash; W_2 = Weight of sample only; W_1 = Weight of crucible.

Starch and sugar

Starch after hydrolysis to sugars and free sugar contents were determined by colorimetric method of phenol-sulfuric acid reaction with sugars (Dubois et al., 1956). About 0.020 g of finely ground sample was weighed using a weighing balance (Ohaus PA214, Switzerland) into centrifuge tubes and wetted with 95% ethanol (1 ml). To the 1 ml of 95% ethanol, 2 ml of distilled water was added, followed by 10 ml of hot ethanol. The mixture was vortexed and centrifuged (Gallenkamp model 90-1, England) at about 2,000 rpm for 10 min. The supernatant was collected and used for free sugar analysis and the residue for starch analysis.

For starch determination, 7.5 ml of perchloric acid was added to the residue and allowed to hydrolyze for 1 hr. The hydrolyzed mixture of perchloric acid and residue was diluted to 25 ml with distilled water filtered through Whatman No. 2 filter paper. From the filtrate, 0.05 ml was taken, made up to 1 ml with distilled water, and vortexed: the colour was developed by adding 0.5 ml of phenol followed by 2.5 ml of concentrated H_2SO_4. The mixture was vortexed and allowed to cool to room temperature; the absorbance was read at 490 nm. on a spectrophotometer (Model Spectronic 601, Milton Roy Company, USA). Next, about 0.2 ml of the aliquot was taken from the supernatant and made up to 20 ml with distilled water, after which 0.5 ml of phenol and 2.5 ml of concentrated H_2SO_4 was added. This was allowed to cool, and the absorbance was read at 490 nm.

To get the standard glucose solution, 0.01 g of D-glucose was weighed into a 100 ml volumetric flask. The contents were dissolved and made up to the 100 ml mark with distilled water, after which quantities of the stock solution (100 μg/ml glucose) were dispensed into test tubes (0.1, 0.2, 0.3, 0.4, and 0.5 ml), and each was made up to 1.0 ml with distilled water. This corresponds to 10, 20, 30, 40, and 50 mg/ml glucose. This was followed by adding 0.5 ml of 5% of phenols and 2.5 ml of concentrated H_2SO_4. The solution was vortexed and cooled; the absorbance was read at 490 nm. A graph (standard glucose curve) of absorbance against concentration was plotted to determine the slope, and the intercept was used in calculating sugar and starch contents. The regression coefficient and R^2 of the standard glucose curve is shown in Figure 3.

$$\text{Percentage sugar content} = \left(\frac{\text{Abs.} - \text{Intercept} \times \text{Dilution factor} \times \text{Volume}}{\text{Weight of sample} \times \text{slope} \times 10\,000}\right) \times 100$$

Where: Abs. = Absorbance; Dilution factor = 5; Volume = 20 ml.

$$\text{Percentage starch content} = \left(\frac{\text{Abs.} - \text{Intercept} \times \text{Dilution factor} \times \text{Volume} \times 0.9}{\text{Weight of sample} \times \text{slope} \times 10\,000}\right) \times 100$$

Where: Dilution factor = 20; Volume = 25 ml.

Note: The slope and intercept used for the calculations were from the standard glucose curve.

pH-value

Samples (5 g) were suspended in de-ionized water for 5 min at a ratio of 1:5 (w/w), and pH was measured using glass electrode attached to a digital pH meter (Orion Research Inc., USA, Model 720A) (AOAC, 2000).

Cyanogenic potential

The sample (30 g) was homogenized in 250 ml of 0.1 M orthophosphoric acid; the homogenate was centrifuged, and the supernatant was extracted. About 0.1 ml of the extract was treated with linamarin (enzyme) standard to get the total cyanogenic potential (CNP). Another assay was run with 0.1 ml of extract, but 0.1 ml of 0.1 M phosphate buffer (pH 6.0) was used to give the non-glucosidic CNP. A third assay was then run with 0.6 ml of extract added to 3.4 ml of McIlvaine buffer (pH 4.5). It was properly mixed, and 0.2 ml of 0.5% chloramine T and 0.8 ml of colour reagent was added to give the free cyanogen (Essers et al., 1993). A standard curve was then obtained by plotting absorbance values (y-axis) against the standard concentration (x-axis): linamarin = 125 ml/(sample weight × 0.01093); non-glucosidic cyanogen = 125 ml/(sample weight × 0.03176); free cyanide = 125 ml/(sample weight × 0.04151). The absorbance was measured at 640 nm on a spectrophotometer (Model Spectronic 601, Milton Roy Company, USA).

2.4 | Statistical analysis

Statistical Package for Social Sciences (SPSS) software (version 21.0) was used for the analysis of variance (ANOVA), separation of the means (using Duncan's Multiple Range Test at $p < .05$), and Pearson correlation, of the data generated in duplicates.

3 | RESULTS AND DISCUSSION

3.1 | Scoping study

There is a diversity of cassava varieties in the surveyed communities (Table 1). Based on many years of commercial cassava processing activities, the operators of the community processing centres identified and adopted specific varieties for fufu or gari production. The adoption decision mainly was based on processing characteristics and consumers' quality preferences for the two products. Varieties mostly adopted for producing gari include *Oyarugba*, *Akingbade*, *Odongbo*, *Ege igede*, *Egedudu/Babadudu*, *Agric*, *Kokumo*, *Arubielu*, *Babaota*, *Ofege*, and *Idipo*. The local varieties adopted for fufu production are *Paroba*, *Sharp or Abeokuta*, *Dangaria*, *Egedudu*, *Idileruwa*, *Mokoshokun*, *Okoyawo (Oko-Iyawo)*, *Kabiesi*, *Olokanga* and *Paroba*. The improved varieties generally adopted for gari are TMS 980002 and TME 419. Most of these varieties were similarly identified by Teeken et al. (2018) as the top preferred varieties by men and women growers of cassava in the same region, Southwest of Nigeria, where the current study was conducted. However, while the current was on commercial community cassava processors, Teeken et al. (2018) focused on smallholder cassava growers or farmers.

Processors claimed that Odongbo is a local variety and that ITA and ITA1 are improved varieties. Although Odongbo is genuinely a land race released in Nigeria as TME 2 (Table 2), there is no documentary evidence to support the processors' classification of ITA and ITA1 as improved. Also, these two varieties have not been documented in previous studies in Nigeria. Therefore, for the rest of the discussions, 'Improved variety' is used as a group name but not as a collection of genuinely improved varieties.

The most widely adopted variety for gari is Odongbo. Processors in at least two communities adopted Agric, Akingbade, Arubielu, Ege igede, Egedudu, Kokumo, and Oyarugba for gari production (Table 1). TME 419 and TMS 980002, Idipo, Ofege, Babaota, Ege dudu, Egedudu/Babadudu were adopted in at least one community for producing gari. For fufu production, Egedudu was the most widely adopted by the various communities. At least six communities adopted Egedudu for producing fufu. Dangaria, Idileruwa, Paroba, ITA, Mokoshokun, Odongbo, and Sharp/Abeokuta were adopted by at least two community processing centres. The reasons provided by the operators of the community cassava processing centres for their preferences are:

a. *Idileruwa* and *Okoyawo* were not suitable for fufu because of their high-water contents, lowering the product yield. However, gari and fufu made from the varieties are more acceptable to the consumers during the dry season, hence influencing adoption by the processors during the dry season, especially for Okoyawo.
b. According to the processors, yellow-fleshed cassava varieties have good processing characteristics for fufu. However, the consumers negatively perceive the yellow color for fufu and are less receptive to *fufu* made wholly from yellow cassava. Wossen

TABLE 1 Cassava variety desirability assessment of gari and fufu

Community cassava processing center	Longitude, latitude	Gari		Fufu	
		Good	Not good	Good	Not good
Akinyele and Army Barracks-Ojoo (Gari and Fufu)	3.8431622, 7.530234	Oyarugba, Akingbade, Odongbo, Ege igede, Egedudu/Babadudu, Agric, Kokumo, Idipo, Arubielu, Babaota, Ofege, TMS 980002, TME 419	Okoyawo, Ege Owini, Yellow cassava	Paroba, Sharp/Abeokuta, Dangaria, Egedudu, Idileruwa, Mokoshokun, Kabiesi, Olokanga, ITA 1, ITA	Odongbo, Okoyawo, Idileruwa, Yellow cassava
Barika (Fufu)	3.9062254, 7.4494099	NA	NA	Paroba, Egedudu, Sharp/Abeokuta, ITA	Odongbo, Okoyawo
Omi-Adio (Fufu)	3.6672348, 7.4071751	NA	NA	Dangaria, Egedudu, Idileruwa, Mokoshokun	Idileruwa, Yellow cassava, ITA
Iroko (Gari and Fufu)	3.9158005, 7.6547221	Oyarugba, Akingbade	NA	Okoyawo, Oyarugba, Akingbade	NA
Motunde (Gari and Fufu)	3.8699632, 7.4567466	Odongbo, Ege dudu	Okoyawo	Odongbo, Egedudu	Okoyawo
Fiditi (Gari and Fufu)	3.8974347, 7.7111448	Ege igede, Egedudu, Agric, Kokumo	Ege-Owini	Ege igede, Egedudu, Agric, Kokumo	Ege-Owini
Ilora (Gari and Fufu)	3.8070372, 7.7910107	Egedudu, Arubielu, Odongbo	Okoyawo, Ege-Owini	Egedudu, Arubielu, Odongbo	Okoyawo

Abbreviation: NA, Not available.

TABLE 2 Processors' classification of local and improved varieties of cassava in Southwest of Nigeria

S/N	Local name	Community processors' classification	Scientific classification	†Scientifically validated variety name or population	Original name	Origin/source (developing research institution)	Comment
1	ITA	Improved	No information	NA	NA	NA	NA
2	ITA 1	Improved	No information	NA	NA	NA	NA
3	Odongbo (Odungbo)	Local	Local	NICASS 9	MS 3; [β]TME 2)	IAR&T	Released in 1986
4	Babaota, Dangaria, Idipo, Iparoba/ Paroba, Kabiesi, Kokumo, and Mokoshokun	NA	NA	NA	NA	NA	NA
5	Agric, Babadudu, Egedudu, Olokanga (Mole kan aga)	Local	Local	†TMEB131 (C-2 Cape Verde), TMEB2050, TMEB994	NA	NA	NA
6	Arubielu	Local	Local	†BEN 86019, Caricass_Toma (231, 233), TMEB3, TMEB 4, TMEB 7, TMEB 12, TMEB 14 (235); TMEB9 (236)	NA	NA	NA
7	Idileruwa	Local	Local	†TMEB1	Antiota	NA	NA
8	Oko-Iyawo (Okoyawo)	Local	Local	†TMEB3, TMEB4, TMEB7, TMEB12 and TMEB14	NA	NA	NA
9	Ofege or Texaco	Local	Improved	†TMS 30572	NA	NA	NA
10	NA	Improved	Improved	NICASS 20	TME 419	IITA	Released in 2005
11	NA	Improved	Improved	NICASS 29	TMS 98/0002	IITA, NRCRI, RMRDC	Released in 2006
12	NA	Improved	Improved	NICASS 31	TMS 96/1089A	IITA, NRCRI	Moderate level of βcarotene; Released in 2008

Abbreviations: IAR&T, Institute of Agriculture Research & Training; NA, Not Available; NRCRI, National Root Crop Research Institute; RMRDC, Raw Material Research and Development Council.

Source: https://www.seedportal.org.ng/index.php; β https://my.iita.org/accession2/accession/TMe-2; †Cassava DNA Cassava DNA Fingerprint database (Wossen et al., 2017, 2018).

TABLE 3 Gari and fufu yield from cassava varieties classified by processors as improved and local

	Product yield (%)	
Variety	Gari	Fufu
Improved		
ITA[a]	26.0 ± 0.14e	27.6 ± 0.07b
ITA1[a]	30.0 ± 0.04b	27.6 ± 0.04b
TME 419	30.0 ± 0.07b	22.4 ± 0.07f
TMS 980002	40.0 ± 0.04a	36.0 ± 0.03a
Mean	31.5	28.4
Local		
Kabiesi	28.0 ± 0.04c	23.5 ± 0.42e
Sharp	22.5 ± 0.01f	15.0 ± 0.01g
Paroba	26.0 ± 0.14d	23.6 ± 0.04d
Okoyawo	30.0 ± 0.04b	24.8 ± 0.04c
Mean	26.6	21.7
p level	***	***

[a]Community Processors' classification as improved varieties but no scientific evidence was found.

***Significant at $p < .05$; Means with the same letter within the same column are not significantly different ($p < .05$). Results are means of triplicate processing experiments; ±Standard deviation.

et al. (2017) made a similar observation on the use of yellow varieties by farmers. To use yellow-fleshed roots for fufu production, the processors mix yellow-fleshed varieties with white-fleshed varieties to give a cream colored *fufu*, which is more acceptable to the consumers.

c. According to the processors' trade knowledge, ITA variety has "five variations". All the communities except one, Omi-Adio, indicated that all the ITA variations are suitable for fufu and are adopted for producing the product. This claim of different variations of a cassava variety could not be supported by science, in any case. However, the five ITA variations were not specifically mentioned by the processors during the study.
d. ITA and *Okoyawo* were described as unsuitable for fufu in Akinyele, Barracks, Barika, Omi-Adio and Ilora communities.
e. Egedudu was observed to have delayed postharvest physiological deterioration property, which is a desirable trait in fresh roots. In addition, the delayed colour change in the root tissue is an outstanding quality trait in cassava processing because consumers associate a white colour with excellent *fufu* quality.

There is an indication that cassava processors refer to improved varieties as local and in some cases, refer to truly local varieties as improved, just as cassava growers do (Bentley et al., 2017). For example, it has been observed that cassava growers refer to several different varieties as Oko-Iyawo (Bentley et al., 2017). Similarly, several different cassava varieties are likely called Agric or Yellow cassava in different processing communities. However, further studies may be needed to use DNA testing to identify or differentiate these varieties and map them to their actual processing traits to specific market segments.

In addition, the study revealed that consumer preferences influence the adoption decisions of the community cassava processors and varietal preferences vary between communities and market type (Table 1). A variety may be considered suitable for a particular product by a community but considered unsuitable for the same product in another community. While some varieties are considered suitable for both products, other varieties are considered suitable for one or the other product by processors. Examples for each of these positions are reported in this study.

Previous studies that focused on the perception of smallholder cassava farmers found that the growers attached substantial priority to agronomic traits such as high yield, root size, early maturity, and dry matter content (Teeken et al., 2018). According to Spencer and Ezedinma (2017), the willingness of farmers to adopt and continue to grow new or improved varieties compared to the local varieties increases with root yield differences between varieties. The profitability arising from increased root yield from an improved variety may prompt more growers to adopt the new variety. Wossen et al. (2017) reported that the significant determinants of the dis-adoption of cassava varieties by smallholder farmers include distance to market due to the bulkiness of some of the varieties, lack of planting material, availability of better-improved varieties, and pest and disease problems. One of the main reasons farmers dis-adopt improved varieties is the availability of better varieties (Wossen et al., 2017). Tarawali et al. (2012) also observed that farming experience and root yield contribute to farmers' willingness to adopt an improved variety. Nonetheless, the availability of the local market to buy the entire farm output at acceptable prices is an essential factor for most commercially oriented farmers (Spencer & Ezedinma, 2017).

The current study, which focused on commercial processors revealed that in a commercialized cassava farming and processing system, the quality traits of the products made from a variety influence market opportunity for the processor. The quality traits ultimately drives the processor's variety adoption decision, and consequently determines the market opportunity accessible to the grower and thus may drive the variety adoption decisions of a commercialized grower. This finding agrees with the market-related observation of Spencer and Ezedinma (2017). On the other hand, in a food-security focused farming system, the quality preferences of the cassava grower tend to determine the adoption decision.

3.2 | Product yield

Knowledge of product yield is an essential physical and economic factor in screening varieties for products (Awoyale et al., 2020) and adopting or dis-adoption of a particular variety by the farmers and processors. Although processing characteristics and consumer preferences are important drivers of demand for fresh roots by the processors and marketability of farmers' varieties, root yield remains an essential factor in variety adoption at the farmers level (Teeken et al., 2018). The gari yield from improved varieties is 26.0%–40.0%, with an average of 31.5% of the fresh roots processed. For local varieties, a range of 22.5%–30.0% and an average of 26.6% of the processed fresh roots (Table 3). Likewise, fufu yield from improved varieties was in the range 22.4%–36.0% and an average of 28.4%, while for local varieties, product yield ranges from 15%–24.8% with an average of 21.7%. Product yields from cassava varieties classified as improved are significantly higher ($p < .05\%$) than from local varieties for both gari (31.5% and 26.6%, respectively) and fufu (28.4% and 21.7%, respectively) (Table 3). This factor has crucial economic importance for processors and may have contributed to adopting the varieties such as TME 419 and TME 980002 by Akinyele and Army Barracks-Ojoo community gari processors, and ITA and ITA 1 by fufu processors in Akinyele, Army Barracks-Ojoo, and Barika communities (Table 1). The result suggests that high product yield is a priority for adoption and could be a factor processor used to classify varieties with unknown identity as improved casually.

Sharp, a local variety, gave a low gari yield of 22.5% and 15.0% fufu yield. Surprisingly, the variety is still adopted for fufu production by processors at Akinyele, Army Barracks-Ojoo, and Omi-Adio community processing centers (Table 1). This confirms that in addition to product yield, other criteria are considered by processors to adopt a variety for making a processed product. The eating quality, storability and shelf stability primarily controlled by the functional, pasting, and chemical properties of the variety are other possibilities (Wossen et al., 2017). There was no significant difference ($p > .05$) in the yield of gari produced from Okoyawo and the yield from ITA1 and TME 419. Despite the relatively higher yield obtained during the laboratory assessment (which was done during the dry season) (Table 3), Okoyawo is not popular among many community cassava processors, especially during the rainy season.

3.3 | Functional properties of cassava products

Functional properties affect how food behaves during preparation for consumption and its end-use (Awoyale et al., 2015). The most important functional properties of gari and fufu are water absorption capacity (WAC), Bulk density (BD), dispersibility, swelling power (SWP), solubility index (SI), and the least gelation concentration (LGC). These properties may offer important information regarding products' eating quality and serve as laboratory predictors of product quality and processors' acceptability of a new variety.

Table 4 shows the functional properties of gari and fufu produced from improved and local varieties. The mean of the functional properties of the products produced from the improved varieties are 491.4% and 143.9% WAC, 53.7% and 46.8% BD, 9.6% and 11.4% SWP, 11.3% and 8.8% SI, 26.0% and 77.1% dispersibility, and 16.3% and 16.3% LGC for gari and fufu, respectively. For the local varieties, these were respectively 613.0% and 184.0% WAC, 55.7% and 59.0% BD, 9.0% and 11.2% SWP, 7.1% and 5.6% SI, 30.0% and 76.3% dispersibility, and 16.3% and 13.8% LGC for gari and fufu (Table 4). There was no significant difference between the means of the functional properties of the local and improved varieties for gari or fufu ($p > .05$). However, significant varietal differences exist ($p < .05$) within each group (as classified by the community processors in Table 4). Thus, it is observed that the average WAC of gari (491.4%–613.0%) is higher than for fufu (143.9%–184.0%). Conversely, the range of the dispersibility of fufu (76.3%–77.1%) is higher than for gari (26.0%–30.0%).

Water absorption capacity is an essential property for most starchy foods, which the low WAC in some of the gari samples may be attributed to differences in the granule structure, and degrees of

TABLE 4 Functional properties of gari and fufu produced from improved and local cassava varieties

	Water absorption capacity (%)		Bulk density (%)		Swelling power (%)
Varieties	Gari	Fufu	Gari	Fufu	Gari
Improved					
ITA	587.0 ± 3.37e	152.4 ± 0.03d	53.9 ± 0.01c	63.7 ± 0.01b	9.0 ± 0.52bc
ITA1	168.8 ± 0.66h	131.1 ± 0.45g	53.9 ± 0.00c	15.4 ± 0.01f	11.4 ± 0.13a
TME419	595.0 ± 0.79d	155.6 ± 1.41c	50.1 ± 0.02d	53.9 ± 0.01e	8.5 ± 0.28d
TMS 980002	614.9 ± 0.25c	136.7 ± 0.81f	57.2 ± 1.65b	53.9 ± 0.01de	9.4 ± 0.00b
Mean	491.4	143.9	53.7	46.8	9.6
Local					
Kabiesi	676.5 ± 2.22a	126.0 ± 2.60h	52.7 ± 1.37c	53.9 ± 0.01de	9.5 ± 0.38b
Okoyawo	577.5 ± 3.05f	159.1 ± 0.74b	63.6 ± 0.00a	58.4 ± 0.01c	9.0 ± 0.01bc
Paroba	568.3 ± 0.74g	308.7 ± 0.17a	56.4 ± 1.14b	70.0 ± 0.01a	8.5 ± 0.12c
Sharp	629.9 ± 1.24b	142.0 ± 0.96e	50.0 ± 0.00d	53.9 ± 0.01d	8.8 ± 0.16bc
Mean	613.0	184.0	55.7	59.0	9.0
T-test ($df = 14$)					
t-value	1.68	1.44	0.92	1.66	1.35
p improved × local varieties	NS	NS	NS	NS	NS

Note: NS-Not significant ($p > .05$). Means with the same letters in the same column are not significantly different ($p < .05$)

availability of the water binding sites among the samples does not only depend on starch granule sizes and solubility, but also granule composition and the internal hydrogen bonding strength and crystalline lamella of the starch granules (Tian et al., 1991). Consumers, and by inference processors, attribute high water absorption capacity to the good quality of gari. Gari from Kabiesi had a significantly higher ($p > .05$) WAC (676.5%) than the gari from all the other varieties followed in decreasing order by Sharp (629.9%), TME 980002 (614.9%) and TME 419 (595.0%). WAC of gari from ITA1 (168.8%) was significantly lower than for all the gari samples. Also, the WAC of gari from Okoyawo (577.5%) and Paroba (568.3%) are low. (Xian et al., 2020).

Similarly, the WAC of fufu from Paroba (308.66%) was significantly higher ($p > .05$) than for all the other varieties followed in decreasing order by Okoyawo (159.12%), TME 419 (155.6%), and ITA (152.4%). On the other hand, the WAC of fufu from Kabiesi (126.0%) was significantly lower ($p > .05$) than for all the fufu samples, and the WAC of fufu from TMS 980002 (136.7%) and ITA1 (131.1%) are low.

Within the improved varieties (processors' classification), high WAC may have been one of the quality traits favoring the adoption of TMS980002 and TME 419 for producing gari. On the other hand, Okoyawo was disliked for gari despite the high WAC and high product yield, and it is also disliked for making fufu by almost all the community processing centers except Iroko, noting that the fufu yield is also not high. WAC did not seem to influence the adoption of ITA 1, ITA, Sharp and Kabiesi for producing fufu. On the other hand, the high WAC of the fufu produced from Paroba may have contributed to the acceptability in Akinyele, Barika, and Army Barracks-Ojoo.

The bulk density (BD) of foods is also referred to as packing density. Food with high bulk density is easier to pack, uses less packaging materials as it occupies less space, and is easier and cheaper to transport to the market. Processors may use this criterion to judge the possible marketing cost of a batch of gari or fufu. The BD of gari from Okoyawo was significantly higher ($p > .05$) than for all the other samples (63.6%). These were followed by TMS 980002 and Paroba (56.4%–57.2%), and ITA, ITA1 and Kabiesi (52.9%–53.9%). The final moisture content may significantly influence BD values, the particle size of foods (Romuli et al., 2017), and change depending on how the material is handled. This is true in gari processing, whereby the cassava grating step can influence the final particles size of gari, and the roasting process influences the agglomeration of gari. Hence BD of gari is not an entirely intrinsic property of cassava variety. The ability of the processor to manipulate the roasting operation to obtain uniform and smaller particle size gari, thereby lowering the packing and transportation cost, could be a major factor in consumer likeness of the gari. This may explain the reason the low BD value of TME 419 (50.1%), a well-adopted variety for gari, is not significantly different from BD for Sharp (50.0%), a variety not adopted by any processing community for processing gari (Table 1). A similar scenario was observed for fufu. The BD of Paroba and ITA, two varieties adopted for fufu by two community processing centers, had BD values (70.0% and 63.7%, respectively) significantly higher than all the other samples. These were followed by Okoyawo, a variety disadopted for producing fufu by most community processing centers (Akinyele, Army Barracks_Ojoo, Barika, Motunde, and Ilora) having a BD (58.4%) higher than ITA 1 (15.4%), Kabiesi (54.0%) and Sharp (53.9%), which are more widely adopted for producing fufu. Finally, ANOVA results suggest that BD may not be a strong indicator of processors' adoption decision of a variety, but each variety and each batch of processed product is better assessed based on its quality traits.

	Solubility index (%)		Dispersibility (%)		Least gelation concentration (%)	
Fufu	Gari	Fufu	Gari	Fufu	Gari	Fufu
11.1 ± 0.02c	20.4 ± 0.35a	18.6 ± 0.51a	24.5 ± 0.71e	74.0 ± 0.00d	20.0 ± 0.01b	10.0 ± 0.02c
11.0 ± 0.03c	8.7 ± 0.35b	10.4 ± 0.06b	30.0 ± 0.00d	83.5 ± 0.71a	15.0 ± 0.01c	20.1 ± 0.01a
11.0 ± 0.06c	7.6 ± 0.26c	3.5 ± 0.31ef	34.5 ± 0.71c	76.0 ± 0.00b	10.0 ± 0.01d	20.1 ± 0.01a
12.4 ± 0.17b	8.4 ± 0.03b	2.8 ± 0.25g	15.0 ± 0.00g	75.0 ± 0.00c	20.0 ± 0.01b	15.1 ± 0.07b
11.4	11.3	8.8	26.0	77.1	16.3	16.3
13.5 ± 0.66a	7.6 ± 0.33c	7.6 ± 0.08d	19.5 ± 0.71f	74.0 ± 0.00d	10.0 ± 0.01d	15.01 ± 0.01b
10.6 ± 0.19 cd	5.4 ± 0.28e	2.4 ± 0.04g	36.0 ± 0.00b	84.0 ± 0.00a	15.0 ± 0.01c	5.08 ± 0.11d
10.4 ± 0.00 cd	8.6 ± 0.01b	8.4 ± 0.37c	40.0 ± 0.00a	75.0 ± 0.00c	20.1 ± 0.04a	20.08 ± 0.04a
10.1 ± 0.15d	6.8 ± 0.03d	3.9 ± 0.59e	24.5 ± 0.71e	72.0 ± 0.00e	20.0 ± 0.01b	15.01 ± 0.01b
11.2	7.1	5.6	30.0	76.3	16.3	13.8
0.39	2.06	1.25	0.96	0.39	0.01	0.98
NS	NS	NS	NS	NS	NS	NS

TABLE 5 Pasting properties of gari and fufu produced from local and improved cassava varieties

Varieties	Peak viscosity (RVU)		Breakdown viscosity (RVU)		Final viscosity (RVU)
	Gari	Fufu	Gari	Fufu	Gari
Improved					
ITA	450.5 ± 16.67b	756.1 ± 12.44 cd	101.2 ± 9.67b	348.0 ± 1.94d	546.5 ± 3.36ba
ITA1	584.4 ± 1.35a	823.9 ± 23.27a	370.1 ± 34.94a	353.56 ± 8.49d	286.9 ± 34.83e
TME419	408.0 ± 9.49c	838.5 ± 8.78a	53.3 ± 0.71c	495.9 ± 2.00b	545.3 ± 11.08a
TMS980002	309.4 ± 4.42e	779.5 ± 28.52c	51.4 ± 3.83c	400.8 ± 14.38c	380.5 ± 0.95d
Mean	438.1	799.5	144.0	399.6	439.8
Local					
Kabiesi	407.4 ± 1.59c	813.3 ± 11.43ab	98.5 ± 5.42b	545.1 ± 11.31a	428.0 ± 7.07c
Okoyawo	357.4 ± 24.22d	815.9 ± 11.43ab	26.9 ± 5.67c	221.5 ± 5.77e	541.7 ± 2.53a
Paroba	381.0 ± 19.80 cd	818.3 ± 7.90ab	98.0 ± 10.20b	509.6 ± 18.38b	461.3 ± 2.23b
Sharp	367.1 ± 17.15d	818.5 ± 19.98ab	42.2 ± 5.13c	420.3 ± 9.43c	484.0 ± 9.72b
Mean	378.2	816.5	66.4	424.1	478.7
T-test (*df*=14) *t*-value	1.56	1.21	1.5	0.47	0.86
p improved × local varieties	NS	NS	NS	NS	NS

Note: Means with the same letters in the same column are not significantly different ($p < .05$).
*$p < .05$; ***$p < .001$; NS, Not significant.

The SWP and SI are measures of the ability of starch to absorb water, swell and leach soluble components. They reflect the extent of associatory forces within the starch granules or the magnitude of the interaction between starch chains within the amorphous and crystalline domains (Awoyale et al., 2020). High swelling power or swelling index depicts higher associatory forces and higher quality in gari. Chan et al. (2009) had reported that both swelling power and solubility properties are influenced by amylose and amylopectin characteristics. According to Sanni et al. (2001), high amylose content increases solubility. Also, SWP may be influenced by temperature and mineral constituents of the food item, such as phosphate that increases water absorption in food granules. According to Awoyale et al. (2020), a good quality gari would typically swell three times its original volume or more. ANOVA revealed no significant difference in SWP between the two groups of improved and local varieties (processors' classification) but differences among varieties were observed within the groups. Gari from ITA 1 has the highest SWP (11.4%) followed by Kabiesi (9.5%), TMS 980002 (9.4%), Okoyawo (9.0%), and ITA (9.0%). Fufu from Kabiesi had a significantly ($p > .05$) higher SWP (13.5%) followed by TMS 980002 (12.4%), while fufu from ITA, ITA1, TME 419, Okoyawo, and Paroba had SWP values that are not significantly different and are in the range 10.4%–11.1%. Thus, the SWP values for fufu are generally higher than the SWP of gari samples from the corresponding varieties. As ITA, ITA 1 and Kabiesi were not widely adopted for gari by the community processing centers, this quality trait likely did not have a strong influence on processors to favor the adoption of those varieties. On the other hand, SWP may have influenced the adoption of Kabiesi, ITA, ITA 1, and Paroba by the processors for producing fufu on account of the high SWP values.

Exemptions were, however, observed for Okoyawo and some improved varieties such as TMS980002 and TME 419, which were not adopted for fufu in Akinyele and Army Barracks-Ojoo where they are exclusively used for gari production. Possibly these improved varieties were selected at the breeding stage for their other gari quality traits. Implicitly, Okoyawo could be considered to have a dis-adoption outcome over the years because, despite the high functional properties (WAC of the fufu, BD of the gari and fufu, and SWP of the gari and fufu), it was assessed as not suitable for gari or fufu by almost all the processing communities (Table 1). In this study, the average SWP of fufu samples were generally higher than the SWP of gari for both groups, a factor that may have resulted from the powdery nature of fufu compared to the granular structure of gari. Solubility depicts the ease of water penetration into the constituents of the starch granules of flour (Ikegwu et al., 2009).

The ease of reconstitution of starchy foods in hot water is an essential quality parameter, as this reduces the formation of lumps in the cooked paste (Awoyale et al., 2020). Thus, the higher the dispersibility, the better the way starchy food reconstitutes in water (Kulkarni et al., 1991). As anticipated, fufu exhibited higher dispersibility values than gari, indicating higher dispersibility in water (Table 4). Fufu from Okoyawo and ITA1 had significantly ($p < .05$) higher dispersibility (84.0% and 83.5%, respectively) than the rest of the fufu samples but closely followed by fufu from TME19 (76.0%) and TME980002 (75.0%). On the other hand, gari from Paroba, Okoyawo and TME19 exhibited the highest dispersity with 40.0%, 36.0%, and 34.5%. Hence Okoyawo, Paroba and TME19 were consistent in exhibiting high dispersibility irrespective of the processed products. In practical terms, varieties with high SI may have a lower tendency to form lumps during final cooking to make cooked *fufu* and *eba* (dough from cooked gari). Thus, fufu paste from ITA1, Okoyawo and TME19 may have a lower possibility of forming lumps during cooking. Similarly, gari from Paroba, Okoyawo and TME419 are likely

	Setback viscosity (RVU)		Peak time (min)		Pasting temperature (oC)	
Fufu	Gari	Fufu	Gari	Fufu	Gari	Fufu
526.2 ± 11.01c	197.2 ± 22.98ab	118.1 ± 3.36c	5.4 ± 0.23c	4.4 ± 0.05c	78.7 ± 0.53d	75.2 ± 1.10b-d
619.3 ± 5.36b	72.6 ± 1.48d	149.0 ± 9.43ab	4.2 ± 0.18d	4.3 ± 0.04 cd	76.7 ± 0.07e	75.2 ± 1.13b-d
450.0 ± 14.09d	190.6 ± 0.88ab	107.3 ± 3.30 cd	5.5 ± 0.00c	4.2 ± 0.05d	82.2 ± 1.17c	75.9 ± 0.00a-c
525.7 ± 13.14c	122.5 ± 1.53c	147.0 ± 1.00b	5.8 ± 0.00bc	4.4 ± 0.05c	88.0 ± 0.00b	76.0 ± 0.11a-c
530.3	145.7	130.4	5.2	4.3	81.4	75.6
354.1 ± 0.35f	119.1 ± 0.06 cd	85.8 ± 0.23e	5.6 ± 0.23bc	4.2 ± 0.05d	89.2 ± 1.80b	73.6 ± 0.11d
754.3 ± 11.90a	211.3 ± 27.34a	159.9 ± 8.37a	6.0 ± 0.10ab	5.1 ± 0.00a	92.7 ± 0.04a	76.3 ± 0.64ab
412.1 ± 25.99e	178.3 ± 32.23ab	103.3 ± 0.30d	5.5 ± 0.19bc	4.4 ± 0.05c	88.0 ± 0.07b	77.5 ± 1.17a
498.5 ± 14.79c	159.1 ± 32.00bc	100.3 ± 4.24d	6.3 ± 0.37a	4.6 ± 0.14b	92.8 ± 0.04a	74.4 ± 0.07 cd
504.7	167.0	112.3	5.9	4.5	90.7	75.5
0.41	0.87	1.41	2.48	2.03	5.02	0.17
NS	NS	NS	*	NS	***	NS

to make *eba* (cooked gari) with no lumps, an important quality trait desired by consumers for cooked *fufu* and *eba*. The low tendency of fufu from Okoyawo to form lumps during cooking may have contributed to the adoption of Okoyawo for making fufu at Akinyele, Ojoo, Army Barracks and Iroko (Table 1).

The LGC measures the minimum amount of starchy food needed to form a gel in each volume of water, and the higher the LGC, the more the starch required to form a gel. Thus, a lower LGC will have a favourable economic impact since less quantity of the starchy food would be required to make food gels (Adebowale et al., 2005). Results (Table 4) show that gari and fufu tend to have a similar level of LGC. Meaning that LGC did not differ irrespective of the cassava product or prior partial gelatinization that gari had gone through. Gari samples made from TME419 and Kabiesi had the least LGC value of 10.0%, while fufu from Okoyawo had the least (5.1%) among fufu samples, indicating that the products from these varieties form gel quickly. Therefore, the low LGC property of Okoyawo may have contributed to its adoption for fufu production in Akinyele, Ojoo Army Barracks and Iroko (Table 1). Similarly, the use of TME419 for gari production in Akinyele and Ojoo Army Barracks (Table 1) may also be influenced by the low LGC of the gari.

3.4 | Pasting properties of cassava products from different cassava varieties

The pasting behavior of starch during and after cooking is used in predicting the behaviour of its source. The pasting properties of gari and fufu did not differ between local and improved cassava varieties, except for the peak time ($p < .05$) and pasting temperature ($p < .001$) (Table 5). Peak viscosity is the maximum viscosity reached during the cooking of starchy foods. It contributes to the texture of the cooked starchy dough (Ikegwu et al., 2009). However, the texture of cooked starchy foods may depend on the quantity of water used during reconstitution and the temperature and time spent for the gelatinization (Newport Scientific, 1998). Irrespective of variety, fufu exhibited a higher range of peak viscosity (799.5–816.5 RVU) than gari (378.1–438.1 RVU), implying that cooked fufu tends firmer dough than *eba* (cooked gari). At the same time, the range of peak viscosities of fufu from various varieties are close and generally more consistent in terms of peak viscosity irrespective of processors' classification (local or improved). Gari exhibited a wider range of peak viscosities. The peak viscosity of gari from ITA 1 (584.4 RVU) was significantly higher than for the rest. The gari from TMS 980002 (309.4 RVU) exhibited the least peak viscosity among the improved varieties while Okoyawo (357.4 RVU) and Paroba (381.0 RVU) had the least among the local varieties. Hence, processors whose consumers prefer firm-textured *eba* and *fufu* dough may adopt ITA1 for the two products, while processors whose end-users (consumers) prefer soft textured *eba* and *fufu* dough may adopt TMS980002 for gari and possibly ITA for fufu (756.1 RVU) because of their low peak viscosities (Table 5). Considering the adoption of TMS980002 to produce gari at Akinyele and Ojoo Army Barracks (Table 1), despite its lowest peak viscosity value, it could be inferred that end-user of gari produced by processors at these locations prefer soft textured *eba*, resulting in the processors' adoption of these varieties for gari. Correlation analysis suggests that peak viscosity and WAC of the gari are significantly negatively correlated ($p < .01$, $r = -0.84$) while the swelling power (SWP) is significantly positively correlated with WAC ($p < .05$, $r = 0.74$) (Table 7).

Breakdown viscosity is an index of the ability of starchy foods to withstand high temperatures and sheer stress. The higher the

TABLE 6 Chemical composition and pH value of gari and fufu produced from local and improved cassava varieties (dry basis)

	Ash content (%)		pH value		Sugar content (%)		Starch content (%)		Cyanogenic potential (mg HCN/kg)	
Varieties	Gari	Fufu	Gari	Fufu	Gari	Fufu	Gari	Fufu	Gari	Fufu
Improved										
ITA	1.8 ± 0.02b	0.3 ± 0.03d	4.8 ± 0.01c	5.2 ± 0.02a	0.5 ± 0.08f	2.2 ± 0.09c	49.0 ± 0.23f	52.3 ± 0.35f	4.6 ± 0.21bc	2.7 ± 0.03c
ITA1	1.7 ± 0.10b	0.4 ± 0.00c	6.4 ± 0.02a	5.0 ± 0.01b	8 0.5 ± 0.06b	8.0 ± 0.62a	81.9 ± 0.16b	70.8 ± 0.99b	4.0 ± 0.07bc	4.1 ± 0.04b
TME419	1.5 ± 0.07c	0.5 ± 0.00b	4.8 ± 0.02d	4.7 ± 0.02c	12.8 ±0.05a	1.8 ± 0.09c	82.6 ± 0.86b	43.8 ± 0.95g	0.4 ± 0.11d	0.4 ± 0.11f
TMS 980002	1.8 ± 0.06a	0.6 ± 0.04a	5.1 ± 0.01b	4.8 ± 0.00c	0.4 ± 0.08f	0.0 ± 0.09d	61.9 ± 1.52e	64.5 ± 0.37c	4.4 ± 1.29bc	4.0 ± 0.18b
Mean	1.7	0.5	5.3	4.9	5.6	3.0	68.9	57.8	3.4	2.8
Local										
KABIESI	1.2 ± 0.02d	0.5 ± 0.01ab	4.6 ± 0.01e	4.7 ± 0.01d	0.9 ± 0.06d	0.21 ± 0.07d	84.1 ± 0.27a	87.1 ± 0.10a	5.5 ± 0.01ab	0.8 ± 0.08e
Okoyawo	1.8 ± 0.04ab	0.3 ± 0.00e	4.8 ± 0.02c	4.3 ± 0.00f	0.4 ± 0.11f	0.04 ± 0.01d	66.1 ± 1.29d	57.2 ± 0.69e	7.7 ± 0.01a	5.1 ± 0.03a
Paroba	1.3 ± 0.04d	0.2 ± 0.00e	4.9 ± 0.01c	4.4 ± 0.03e	1.9 ± 0.07c	1.67 ± 0.11c	63.9 ± 0.47d	61.1 ± 0.04d	4.8 ± 1.70b	2.4 ± 0.05d
SHARP	1.2 ± 0.03d	0.3 ± 0.01e	4.8 ± 0.01c	5.0 ± 0.02b	0.7 ± 0.04e	2.85 ± 0.04b	68.5 ± 1.22c	63.2 ± 0.41d	2.3 ± 1.14 cd	0.5 ± 0.01f
Mean	1.4	0.3	4.8	4.6	1.0	1.2	70.6	67.2	5.1	2.2
T-test (*df* = 14)										
t-value	2.97	2.45	1.30	2.73	2.26	1.50	0.52	1.58	1.85	0.61
p improved × local varieties	**	*	NS	*	*	NS	NS	NS	NS	NS

Note: Means with the same letters in the same column are not significantly different ($p < .05$).

*$p < .05$; **$p < .01$; NS, Not significant.

TABLE 7 Pearson correlation of the functional properties with the pasting and chemical properties of gari and fufu flour

Parameters	Product yield	Water absorption capacity	Bulk density	Swelling power	Solubility index	Dispersibility	Least gelation concentration	Oil absorption capacity
Gari								
Peak viscosity	−0.22	−0.84**	−0.27	0.76*	0.29	0.18	−0.24	−0.24
Trough viscosity	−0.44	0.70	−0.14	−0.78*	0.23	0.15	−0.18	0.71*
Breakdown viscosity	0.03	−0.93**	−0.14	0.90**	0.11	0.07	−0.10	−0.49
Final viscosity	−0.51	0.67	0.06	−0.83*	0.22	0.32	−0.04	0.66
Setback viscosity	−0.54	0.57	0.27	−0.83*	0.19	0.47	0.12	0.56
Peak time	−0.01	0.87**	0.12	−0.78*	−0.25	−0.16	0.22	0.44
Pasting temperature	−0.07	0.65	0.33	−0.51	−0.61	−0.05	0.10	0.12
Ash	0.28	−0.38	0.55	0.39	0.15	−0.14	0.14	−0.71*
pH value	0.21	−0.93**	−0.06	0.91**	−0.23	0.05	−0.08	−0.61
Sugar	0.09	−0.47	−0.45	0.21	−0.16	0.38	−0.57	0.07
Starch	0.06	−0.28	−0.35	0.36	−0.63	0.09	−0.82*	−0.16
CNP	−0.41	0.02	0.86**	0.15	−0.01	0.02	0.14	−0.57
Fufu								
Peak viscosity	−0.53	0.15	−0.31	−0.22	−0.57	0.30	0.47	−0.26
Trough viscosity	−0.36	−0.25	−0.29	−0.48	−0.12	0.77*	−0.62	0.67
Breakdown viscosity	0.21	0.27	0.20	0.40	−0.03	−0.66	0.72*	−0.70
Final viscosity	−0.27	−0.25	−0.32	−0.43	−0.13	0.80*	−0.59	0.63
Setback viscosity	0.07	−0.22	−0.40	−0.20	−0.15	0.78*	−0.38	0.40
Peak time	−0.51	0.05	0.24	−0.44	−0.30	0.42	−0.79*	0.84**
Pasting temperature	−0.11	0.76*	0.32	−0.48	−0.14	0.28	0.10	0.29
Ash	0.50	−0.49	−0.35	0.80*	−0.12	−0.03	0.34	−0.69
pH value	0.55	−0.47	−0.35	−0.01	0.63	−0.31	0.14	−0.09
Sugar	0.16	−0.12	−0.81*	−0.34	0.37	0.38	0.47	−0.26
Starch	0.16	−0.22	−0.32	0.64	0.00	−0.03	0.09	−0.56
CNP	0.03	0.02	−0.24	−0.13	0.02	0.77*	−0.44	0.34

Abbreviation: CNP, Cyanogenic potential.

*$p < .05$; **$p < .01$.

breakdown viscosity, the lower the ability of starchy food to withstand heating and shear stress (Newport Scientific, 1998). Gari produced from ITA1 (370.1 RVU), and fufu (495.9 RVU) produced from TME419 had high breakdown viscosities compared to the gari produced from TMS980002 (51.4 RVU) and fufu from ITA (348.0 RVU) that had low breakdown viscosities. Therefore, there are indications that among the varieties classified as improved, gari from ITA1 and fufu from TME419 may not withstand heating and shear stress during cooking to *eba* and *fufu* doughs. Newport Scientific (1998) explained that the rate of starch breakdown depends on the nature of the material, the temperature, and the degree of mixing and shear applied to the mixture. The cooked products (*eba* and *fufu* doughs) are likely to become soft with increased cooking temperature and time. The same may apply to gari (98.5 RVU) and fufu (545.1 RVU) produced from Kabiyesi on account of the high breakdown viscosities compared to gari and fufu produced from Okoyawo with low breakdown viscosities of 26.9 RVU and 221.5 RVU, respectively. This also implied that Okoyawo could withstand heating and shear stress during cooking to *eba* and *fufu* and the doughs may become hard after cooking (Table 5). In addition to the heating and shear stress-bearing property of Okoyawo, both its gari and fufu exhibited the highest final viscosities (541.7 RVU and 754.3 RVU, respectively), suggesting the ability to rapidly form a gel after cooking, considering the explanations of Sanni et al. (2006). However, the final viscosity of gari produced from ITA and TME419 are also high and are not significantly different ($p > .05$) from Okoyawo, meaning that gari produced from the two varieties may form a gel quickly when reconstituted in boiling water to make *eba*, like Okoyawo. These sensory properties may have favored the adoption of TME419 for gari production in Akinyele and Ojoo Army Barracks and Okoyawo for fufu production in Akinyele, Ojoo Army Barracks, and Iroko communities (Table 1). Correlation analysis suggests that breakdown viscosity had opposite correlation with swelling power ($p < .05$, $r = 0.90$) and WAC ($p < .01$, $r = −0.93$) of gari for making *eba*. While for fufu, it had direct positive correlation to LGC ($p < .05$, $r = 0.72$) (Table 7). Similarly, a significant negative correlation ($p < .05$, $r = -0.83$) exists between the final viscosity and the swelling power of the gari, while for fufu, final viscosity had a direct correlation with dispersibility ($p < .05$, $r = 0.80$) (Table 7).

The setback values of both the fufu and gari from Okoyawo were highest, suggesting the tendency to quickly retrograde after cooking (although not significantly higher than Paroba, TME419 and ITA for gari or ITA 1 and TMS980002 for fufu). High setback viscosity during cooling of cooked starch represents low resistance to retrogradation or a high tendency to retrograde or weep (Adebowale et al., 2007; Awoyale et al., 2020), an undesirable property in foods, especially in frozen foods. The high tendency for retrogradation may lead to dislike of *fufu* or gari by consumers and could be a militating factor against Okoyawo's acceptability for producing gari and fufu. Setback viscosity of gari was found to be negatively correlated with swelling power ($p < .05$, $r = -0.83$), while setback viscosity of fufu positively correlated with dispersibility ($p < .05$, $r = 0.78$) (Table 7). Supposedly, either of each pair of correlated properties could be used as a proxy to predict the other property in fufu or gari when assessing varieties for quality traits.

The pasting temperature measures the minimum temperature required to cook a given food sample and has implications for the stability of other components in a formulation, and it also indicates possible energy costs for cooking (Newport Scientific, 1998). Again, fufu from Okoyawo had a significantly ($p < .05$) higher pasting temperature (76.3°C) than others (except for Paroba, 77.5°C) and the gari had a significantly ($p < .05$) higher pasting temperature than gari from other varieties except for Sharp (92.8°C). This means higher heating energy requirement and higher cooking cost may be incurred in preparing gari and *fufu* from Okoyawo for the table or consumption (Table 5). However, gari and fufu from all the varieties formed gel below the boiling point of water (75.5–90.7°C). Furthermore, the peak time during the pasting of gari has a significant positive correlation with WAC ($p < .01$, $r = 0.87$) with the swelling power, but negatively correlated with peak time had a negative correlation ($p < .05$, $r = -0.78$) (Table 7). For practical purposes, high peak viscosity property indicates the possibility of forming a firm dough - a desired quality trait for cooked fufu dough (*fufu)* and *eba* dough from gari. On the other hand, high setback viscosity suggests a high tendency of the variety to retrograde or weep after cooling, an undesirable property in cooked fufu and eba dough as observed in the Okoyawo variety.

3.5 | The chemical composition of products from different varieties

The mean of the chemical properties (dry matter basis) of gari and fufu produced from the improved varieties are, respectively, ash 1.7% and 0.5%, pH 5.3 and 4.9, sugar 5.6% and 3.0%, starch 68.9%, and 57.8%, and cyanogenic potential (CNP) 3.4 mg HCN/kg and 2.8 mg HCN/kg (Table 6). The mean of the chemical properties of the gari and fufu produced from the local varieties are, respectively, ash 1.4% and 0.3%, pH value 4.8 and 4.6, sugar 1.0% and 1.2%, starch 70.6% and 67.2%, and CNP 5.1 mg HCN/kg and 2.2 mg HCN/kg (Table 5). The result showed that there was no significant difference ($p > .05$) in the chemical properties of the gari and fufu produced, except for the ash content of the gari ($p < .01$), fufu ($p < .05$), pH value ($p < .05$) of the fufu and the sugar content ($p < .05$) of the gari. However, significant differences were observed within each class of varieties (Table 6).

The ash content of the gari produced from the varieties classified as improved ranged from 1.5% (TME419) to 1.8% (TMS980002). The ash content of the fufu produced from the varieties classified as improved also ranged between 0.3% (ITA) and 0.6% (TMS980002). Likewise, gari from local varieties had ash contents ranging from 1.2% for Kabiesi to 1.8% for Okoyawo. The ash content was higher in the fufu produced from Kabiesi (0.5%) and lower in the fufu from Paroba (Table 6). Ash content reflects mineral status even though contamination during processing could indicate a high concentration in a sample (Baah et al., 2009). The ash content of all the fufu samples falls below 1.50%, which is the maximum limit set by the FAO/WHO (2019).

The pH of gari samples from varieties classified as improved ranged from 4.8 (TME419) to 6.4 (ITA1) and from 4.7 (TME419) to 5.2 (ITA) for fufu samples produced from the group (Table 6). For gari produced from the local varieties, Paroba had the highest pH value (4.9), and Kabiesi had the least (4.6). Fufu produced from Sharp had the highest pH (5.0), and fufu from Okoyawo had the lowest pH (4.3) (Table 6). This implies that TME419 and local Kabiesi tend to produce sourer gari compared to ITA1 and Paroba, which tend to have high pH. Therefore, community processors or end-use markets with preferences for sour gari are likely to adopt the local varieties such as Kabiesi, whereas processors whose end-use market prefers less sour taste are likely to adopt higher pH gari such as ITA1. Similarly, community processors whose consumer preference is for less sour *fufu* may adopt Sharp, while community processors that the consumers or the market prefer a sourer *fufu* taste may adopt Okoyawo for making fufu. The correlation between the pH and the WAC was negative and significant ($p < .01$, $r = -0.98$), while swelling power had a significant positive correlation with pH ($p < .01$, $r = 0.91$) (Table 7).

The textures of *eba* and *fufu* dough are important quality indices linked to starch content (Akingbala et al., 2005). The starch content of the gari produced from varieties groups as improved ranged from 49.0% to 82.6%, with the highest starch content in gari produced from TME419 and the lowest from ITA. The starch content of fufu was highest for ITA1 (70.8%) and lowest for TME419 (43.8%). The starch content of gari produced from local varieties was highest for Kabiesi (84.1%) and lowest for Paroba (63.9%). Fufu produced from Kabiesi (87.1%) also had the highest starch content, and fufu produced from Okoyawo (57.2%) had the least (Table 6). Thus, TME419 and Kabiesi are likely to produce good textured *fufu* because of their high starch contents. Also, Kabiesi may prefer to produce gari and fufu because of its significantly ($p < .05$) highest starch content and potential to give good texture. With the lowest starch contents for producing gari and fufu (66.1% and 57.2%, respectively), Okoyawo may have inferior texture quality of *eba* and cooked *fufu* and is likely to be unacceptable to the consumers. This finding may be another indication of the dislike of Okoyawo by many communities processing centers for making neither gari nor fufu, especially during the rainy season. A significant negative correlation ($p < .05$, $r = -0.82$) was observed between the starch content and the LGC of the gari (Table 7). This link between the low starch content of cassava varieties and the dislike expressed by community processors for gari and fufu from some varieties, such as for Okoyawo, may suggest that the final cooked dough (*fufu* and *eba*) had poor quality dislike by consumers. Practically, starch content is a good proxy for predicting the texture of *eba* and cooked *fufu* from a new variety, considering that low starch content negatively affects the texture quality of *fufu* and *eba*. The significant negative correlation between starch and LGC also suggests that either starch content or LGC may be a good proxy for predicting eba and fufu texture that may result from a new variety. The processor tends to consider high product yields and starch content - two essential quality traits for the processors - for classifying varieties (e.g., TME419 and ITA 1) as improved varieties but with no scientific evidence.

Gari and fufu samples from Okoyawo and TME980002 had the least sugar contents among all the samples, while the gari produced from TME419 and fufu from ITA 1 had the highest sugar contents (12.8% and 8.0%, respectively) (Table 6). The variations in the sugar contents may influence consumer preferences based on sweet tastes. Low sugar content may be unfavorable for a variety in a locality where sweetness is desired in gari and could be favorable to consumers and communities that desire less sweet taste. Both sweetness and sourness are desirable quality traits in gari but to a varying extent depending on the taste preferences of various communities.

A vital safety parameter for the consumption of cassava-based products is the CNP after ingestion (Bradbury & Holloway, 1988; Uyo et al., 2007). Safe products result from cassava roots when adequately processed before consumption (Uyo et al., 2007). The CNP of gari produced from the varieties classified as improved ranged between 0.4 mg HCN/kg (TME419) and 4.6 mg HCN/kg (ITA), whereas the CNP of fufu ranged from 0.4 mg HCN/kg (TME419) to 4.1 mg HCN/kg (ITA1) (Table 6). These gari and fufu CNP values are below the FAO/WHO (2019) limit of 10 mg HCN/kg. Hence there are no safety issues detected for gari or fufu from any of the varieties.

4 | CONCLUSIONS

The study revealed that high product yield, high starch content, high solubility index, high peak viscosity, low setback viscosity, and delayed postharvest physiological deterioration are possible laboratory indicators that could be used as proxies for predicting product quality and variety adoption decisions of cassava processors. Fufu exhibited higher swelling power, solubility index and peak viscosity than gari from the same varieties. Consumer preferred quality characteristics are difficult to measure for several hundreds of new germplasms in the early stages of the breeding cycle. Thus, this study also shows that a cassava variety acceptable in one processing community for making a particular processed product (such as gari and fufu) may not be acceptable for producing the same product in another community due to differences in quality preferences across communities.

Nonetheless, it indicated the lack of homogenuity in quality traits acceptable to different market segments. Hence, in setting breeding objectives, the preffered quality traits of cassava in the different end-use market should be considered. In addition, because processors tend to give multiple names to the same genetic material and possibly give the same name to genetically different cassava varieties, further research is required to use DNA technology to identify the varieties adopted in different end-use market segments and map their quality traits. Such knowledge will guide the future breeding of varieties most suitable for the specific end-use market.

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CONFLICT OF INTEREST

The authors declare that they do not have any conflict of interest.

AUTHOR CONTRIBUTION

Wasiu Awoyale: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing – original draft; Writing – review & editing. **Adebayo Abass:** Conceptualization; Data curation; Formal analysis; Methodology; Project administration; Resources; Supervision; Validation; Writing – review & editing. **Gregory Nwaoliwe:** Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Writing – original draft. **Ademola Ogundapo:** Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Writing – original draft. **Luke O. Olarinde:** Project administration; Supervision; Writing – review & editing. **Olayemi Oluwasoga:** Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Writing – original draft. **James Oyelekan:** Conceptualization; Formal analysis; Investigation; Methodology; Visualization; Writing – original draft.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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