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MORPHOLOGICAL AND CHEMICAL CHARACTERISTICS OF DIFFERENT CASSAVA VARIETIES IN RELATION TO THE QUALITY ATTRIBUTES OF THEIR *GARI* (ROASTED FERMENTED CASSAVA GRITS)

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ABSTRACT

Gari is the most popular cassava product in West Africa. Therefore, the suitability of any cassava root introduced into this region for *gari* production is important. This study determined some selected morphological and chemical characteristics of six cassava varieties (TMS 30001, TMS 30572, TME 419, TMS 98/0505, TMS 98/0581 and Biofortified) being promoted for widespread cultivation in Kwara State, Nigeria. The yield, physical, chemical and sensory attributes of *gari* made from these roots were also investigated. Principal Component Analysis (PCA) was conducted to identify parameters contributing to major sensory variations in the *gari* samples while correlation analysis was adopted to determine relationships between cassava and *gari* properties. Biofortified cassava had the highest root size attributes. Moisture, starch and cyanide contents of the cassava roots were 64.01-77.38%, 31.47-61.94% and 40.52-58.86 mg/kg, respectively. TMS 30001 had highest pulp-to-peel ratio (3.96) and *gari* yield (20.11%). The particle size distributions, angles of repose, pH, and total titratable acidity of the *gari* samples differed significantly ($p \leq 0.05$). Cyanide content of *gari* from TMS 98/0581 was above WHO recommended safe limit of 10 mg/kg while *gari* from TMS 30001 had highest sesnory ratings, except in taste. PCA revealed overall acceptability, taste and colour as the top three sensory components contributing to variation in the *gari* samples. Root size negatively correlated with dry matter, starch content and *gari* yield. It was concluded that the various cassava varieties exhibited some distinct morpholgical and chemical characteristics which influenced their potentials for *gari* production.

Keywords: Cassava; varieties; *gari*; properties; relationship

INTRODUCTION

There are several cassava varieties being promoted for widespread adoption by farmers and *gari* producers in Nigeria **(Abdoulaye *et al.*, 2014).** However, for many of these cassava varieties, little or no information is available on root and *gari* properties, as well as any possible relationships between these traits. Meanwhile, this is essential as *gari* ranks first among popular cassava food products in Nigeria and, indeed, West Africa **(Komolafe and Arawande, 2010),** hence, prior knowledge about the potential quality attributes of this product greatly influences adoption of cassava varieties in the region.

Cassava (*Manihot esculenta* Crantz) is rated the 5th staple food after wheat, corn, rice, and potatoes in terms of world consumption **(Chuasuwan, 2017)**. Its importance in Nigeria can be ascribed to its food security status and economic benefits for crop producing households. Cassava now has the status of a cash and industrial crop, no longer a mere subsistence crop once described as a poor man's food **(IITA, 2013)**. Nigeria was rated the world's largest producer of the cassava with an annual output of 59 million tonnes in 2017 (**Otekunrin and Sawicka, 2017; Wossen *et al.*, 2017**), apparently justifying the earlier "Cassava Initiative" by past President, Olusegun Obasanjo, and the improved cassava varieties released by International Institute of Tropical Agriculture (IITA) **(Phillips *et al.*, 2004).**

It is customary to process cassava root for detoxification, preservation, and modification into various products. Farmers prefer varieties with high root yield, shorter maturity period, better disease resistance and other agronomic advantages **(Bentley *et al.*, 2017)**. This explains why improved varieties of cassava with better disease and pest resistance released by IITA, Ibadan and the National Root Crops Research Institute (NRCRI), Umudike, resulted to increased cassava production in Nigeria **(Nweke *et al.*, 2002)**. Since cassava has become a major source of income for farmers, consumers preferences with respect to cassava products also now greatly influences the choice of farmers, and by extension that of cassava processors. It is thus imperative to carefully select varieties having a wide spectrum of disease resistance, good and stable root yields, and attributes required by end-users' for common products such as *gari*, *fufu*, *lafun*, tapioca, as well as industrial raw materials including starch, chips, pellets, and unfermented flour. On the other hand, the preferences of the processors for a particular cassava variety are largely determined by processing traits like ease of peeling and grating, and economic parameters, e.g., peel-to-pulp ratio and dry matter content **(Bentley *et al.*, 2017)**. Marrying the preferences of the producers, processors and consumers is therefore necessary.

Several studies have investigated the effect of varietal differences on cassava-based products **(Achinewhu *et al.*, 1998; Adebowale *et al.*, 2008; Ikegwu *et al.*, 2009; Maziya-Dixon *et al.*, 2007; Oyewole and Afolami, 2001)**. **Achinewhu *et al.* (1998)** reported that varietal differences had varying effects on the yield, swelling and water absorption properties, as well as acidity level of *gari* made from six newly developed cassava varieties studied in Rivers State, Nigeria. These variations could only have been associated with inherent genetic differences since all the roots were subjected to the same agronomic conditions and processing method. However, no information was reported on the physical and chemical attributes of the roots and how these related with the quality attributes of *gari*.

Gari is a dry, crispy, creamy flaky cassava product. To produce *gari*, cassava roots are peeled, crushed, fermented, sieved and fried. Though there are both national and international specifications for *gari* quality, variations are common due to processing and varietal differences **(Oduro *et al.*, 2000)**. Factors affecting the attributes of *gari* can be classified as extrinsic, e.g., fermentation and *garification*, and intrinsic, which are majorly determined by variety.

In Nigeria, quite a number of cassava varieties are available. For example, **Komolafe and Arawande (2010)** reported over thirty different cultivars, recommended by extension workers to farmers, owing to their per-hectare root yield. However, only few of these, such as *Odongbo* and TMS 30001 (*oko iyawo*) are popular for *gari* production, suggesting that the less adopted varieties possess certain characteristics that do not favour their suitability for *gari* production. This research work was therefore aimed at characterizing the morphological and chemical properties of six cassava varieties being promoted for widespread adoption in Kwara State, Nigeria through Root and Tuber Expansion Programme (RTEP). Other analyses evaluated included some physicochemical and sensory properties of *gari* from these cassava varieties.

MATERIAL AND METHODS

Materials

The cassava varieties (TMS 30001, TMS 419, TMS 30572, TMS 98/0505, TMS 98/0508 and biofortified A) were harvested from RTEP farm in Ajase Ipo, Kwara State. The various cassava varieties at the point of harvest were within their optimum harvest maturity (9-12 months). The harvested roots were packed in jute bags, well labeled and immediately transported to a *gari* production factory in Lajonrin, Ilorin, Kwara State, Nigeria, for processing into *gari*. Sampled tubers from each variety were conveyed immediately to the laboratory for analyses.

Determination of morphological characteristics of six cassava varieties

The root height and diameter of the various cassava roots were determined using a vernier caliper while their weights were determined on a weighing scale. Measurements were taken on ten randomly selected roots per variety and means were calculated.

Chemical analysis of six cassava varieties

Moisture and cyanide contents

Moisture contents were analysed following a previously described procedure by **AOAC (2000)** while cyanide contents were determined according to **AOAC (2005) method.**

Starch contents

The method described by **Eke *et al.* (2010)** was adopted for starch contents determination. Each of the *gari* samples (0.2 g) was centrifuged (Sorvall centrifuge, Newtown, CT, model GLC-1) with 1 mL of 100% ethanol, 2 mL of distilled water and 10 mL of hot ethanol for 10 mins at 2,000 rpm. This was followed by the addition of perchloric acid (7.5 mL) and distilled water (17.5 mL) to the sediment, with 1 hr resting in between; the mixture was then vortexed. Distilled water (0.95 mL), phenol (0.5 mL), and H_2SO_4 (2.5 mL) were added to 0.05 mL aliquot of the solution pipetted into a test tube. The mixture was again vortexed, and left to cool. Reading of absorbance was done on a spectrophotometer (Milton Roy Company), model spectronic 601, which had been pre-caliberated at 490 nm wavelength.

Production of *gari* from six cassava varieties

The cassava roots were processed into *gari* according to the method described by **Karim *et al.* (2009)**. Freshly harvested cassava roots were peeled using sharp stainless knife. This was done as thorough as possible to ensure no fragment of red peel remained. Next was washing of the peeled roots thoroughly in potable water for removal of soils, dirts and other extraneous materials that might be present from peeling operation. Thereafter, the roots were grated with the aid of a diesel-powered locally fabricated motorized grater to obtain smooth mashes which were then packed into porous jute bags, tied and left to ferment for 5 days. After fermentation, the cassava mashes, while still in the jute bags, were pressed in a hydraulic press for few hours. This was expected to have reduced the moisture content of the mashes to 40-50% **(Abass *et al.*, 2012)**. The resulting wet cassava cakes obtained following dewatering were broken with hands and sieved through a hand-woven sieve to remove fibrous materials and lumps. These were then roasted in an earthenware, over wood fire, until dry enough as signaled by creamy colour and crispy hand-feel. The *gari* samples obtained were adequately cooled at room temperature for about 6 hrs before being packaged in high density polyethylene packs for subsequent analyses. Production was carried out in three replicates.

Determination of pulp-to-peel ratio and ease of peeling of six cassava varieties

The weights of both the pulps and peels were taken separately and ratios of these were taken. The ease of peeling of the roots was assessed on a scale of 6, with 1 denoting 'easy to peel' and 6 denoting 'difficult to peel' **(Akingbala *et al.*, 2005)**.

Analyses of *gari* from six cassava varieties

Determination of *gari* yield

This was taken as the percentage weight of the product (*gari*) obtained per weight of unpeeled cassava roots.

i.e., % *gari* yield = $\frac{W2}{W1}$ **X 100%**

W_1 = weight of whole cassava roots

W_2 = weight of *gari*

Determination of physical attributes of *gari*

Colour analysis

Chroma meter (ColourFlex-Diffuse) was used to measure the colour characteristics (L^*, a^* and b^*) of the *gari* samples. L^* represents lightness/darkness, a^* indicates redness/greeness and yellowness/blueness is denoted by b^*. There was a prior caliberation of the instrument using a standardized white plate before being used for colour determination **(Oyeyinka *et al.*, 2019)**. Measurements were taken in triplicates.

Particle size measurement

Each (50 g) of the *gari* samples was placed on a tyler sieve (Endecotts LTD, England) set up according to the order of apertures sizes (4 mm, 3 m, 1.8 m, 1.4 m, 1 m, and 'fine particles'). First at the top was the sieve of 1 mm aperture size while the base pan was at the very bottom. The sieve, which was covered with a lid, was then agitated on a shaker for 10 mins. The various different apperture sized sieves retained different amounts of *gari* particles. The percentage weights calculated from these were then plotted aganst sieve size to arrive at the average particle size **(Udoro *et al.*, 2014)**.

Angle of repose determination

The angles of repose were measured according to the "poured" angle method described by **Lau (2001).** A wide-outlet funnel was affixed 10 cm above the bench on which a piece of paper had been placed. *Gari* sample was poured into the funnel which was then closed, made to flow through and collected on the piece of paper, forming a cone shape. The diameter (D) of the cone and the two sides (l_1 and l_2) were measured with a ruler and the angle of repose was obtained using the formula: Cos $(D/(l_1+l_2))$.

Chemical analyses of *gari* produced from six cassava varieties

AOAC (2000) method was followed to analyse the moisture contents of the *gari* samples. For starch content, the procedure adopted was by **Eke *et al.* (2010)** while cyanide and pH measurements were in line with **AOAC (1990)** method. The total titratable acidity of the samples on the other hand was evaluated as outlined by **AOAC (2005).**

Sensory evaluation of *gari* produced from six cassava varieties

The *gari* samples in their dry particluate form were subjected to a multiple paired comparison test. Fifty panelists, who are conversant with the charactersitic sensory quality of *gari*, were recruited from the Department of Home Economics and Food Sciene, University of Ilorin, Nigeria. Interest of these panelsists in the sensory evaluation was also considered during their screening. Paramters evaluated included colour, aroma, graininess, taste/sourness, texture/dryness, and overall acceptability; and this was done on a Hedonic scale of preference ranging from 1 ('dislike extremely') to 7 ('like extremely').

Statistical analysis

Statistical Package for Social Sciences (SPSS, version 20.0) was employed for the statictical analyses of the results obtained. Significant differences were determined using Analyses of Variance (ANOVA) while Duncan Test (at p 0.05) was used to separate mean values. Principal Component Analysis (PCA) was used to identify variables contributing most variation in the sensory attributes of the samples and correlation analysis was carried out to determine relationships among key parameters.

RESULTS AND DISCUSSION

Morphological properties of six cassava varieties

Significant ($p \leq 0.05$) variations were recorded in the weights of the cassava varieties studied, suggesting that variety significantly ($p \leq 0.05$) affects root size (Table 1). Biofortified cassava had the highest weight (1761 g), followed by TMS 30001, TMS 30572 and TME 419. Cassava roots with high root weights will be preferred by farmers who sell on weight basis. Therefore, the high root weights of TMS 30001, TMS 30572 and TME 419, coupled with their high root yield (i.e., number of roots per plant or hectare) may explain their preference by farmers **(Bentley *et al.*, 2017)**. **Agele *et al.* (2018)** ranked TME 419 and TMS 30572 as top two most high yielding of the ten different cassava varieties studied. On the contrary, the low weights (378 – 391 g) recorded for TMS 98/0505 and TMS 98/051 might hinder their adoption by farmers due to relatively lower commercial potential.

The various cassava varieties had root lengths varying from 22.32 to 37.78 cm (Table 1). Though the results also show that variety significantly ($p \leq 0.05$) affects root length, the difference was not as wide as observed for root weights. Just as noted for weights, TMS 98/0505 and TMS 98/0581 recorded the shortest lengths, implying that small root size and length are some of the traits of cassava varieties in the TMS 98/ 05 series. Cloning from a similar parental cassava variety results to newly developed varieties with similar characteristics **(Alves, 2002)**. Root lengths have vital importance in cassava processing. Cassava peeling during *gari* production is mostly done manually **(Jimoh *et al.*, 2014)** and majorly by women **(Bentley *et al.*, 2017)** and too short cassava roots may be difficult to handle during peeling. However, short root lengths can be of advantage, especially during harvesting and stacking due to less proneness to mechanical damage – one of the leading causes of cassava spoilage. Shorter cassava roots may also be easier to package in sacks.

Table 1 Morphological properties of six cassava varieties

Samples	Mass (g)	Length (cm)	Diameter (cm)
TMS 30001	809.40^{bc} ± 304.05	30.40^{b} ± 3.01	5.75^{bc} ± 0.95
TMS 30572	799.80^{bc} ± 206.35	37.78^{a} ± 2.48	5.72^{bc} ± 0.80
TME 419	1171.00^{b} ± 678.68	29.96^{b} ±5.96	5.32^{bc} ± 0.85
TMS 98/0505	378.40^{c} ± 122.91	22.32^{c} ± 4.28	7.09^{b} ±1.24
TMS 98/0581	391.40^{c} ± 96.35	27.88^{bc} ± 3.88	4.45^{c} ± 0.40
Biofortified	1761.00^{a} ± 691.02	32.14^{ab} ± 5.56	8.89^{a} ± 2.64

Note. Mean ± SD*;* Means values with different superscripts along the same column differ significantly (p≤0.05)

Pulp-to-Peel ratio and ease of peeling of six cassava varieties

The pulp-to-peel ratios of the cassava varieties were between 2.07 for TMS 98/0581 and 3.96 for TMS 30001 (Figure 1). The range of values reported in this study is slightly wider than the 0.288 - 0.312 peel-to-root ratio (i.e., 2.21 – 2.45 pulp-to-peel ratio equivalents) reported by **Kemausuor *et al.* (2015)** for four varieties of cassava studied. Meanwhile, **Akingbala *et al.* (2005)** previously reported 20:80 peel-to-pulp ratio (i.e., 4.0 pulp-to-peel equivalent) for freshly harvested TMS 30572 cassava roots, which is slightly higher than the 3.22 recorded for same variety in this study. Food and Agriculture Organisation noted that for every tonne of fresh cassava, peels in the range of 250 - 300 kg may be obtained **(Kemausuor *et al.*, 2015)**, implying 2.33 – 3.00 pulp-to-peel ratio. Pulp-to-peel ratios are partly determined by the peeling culture of cassava processors, and the type and quality of the intended final product. For example, to produce good quality *gari* from cassava, it is expected that the peel which consists of a corky periderm and the cortex accounting for 0.5-2% and 8-15%, respectively **(Jimoh *et al.*, 2014)** of the whole root would be completely removed. However, for higher *gari* yield and commercial gain, some *gari* producers compromise this practice, even at the expense of good quality product. Aside variety and peeling culture, **Akingbala *et al.* (2005)** noted that difference in moisture content which makes peels stick to the pulp at varying degrees may account for variation in pulp-to-peel ratios. The authors also reported that when some parts of the pulp are rotten or woody, excessive peeling is inevitable. The practical effect of peeling of cassava on the colour and fibrousness of *gari* cannot be overemphasized **(Abass *et al.*, 2012)**.

Just similar to what was recorded from pulp-to-peel ratio analysis, TMS 98/0581 ranked last while TMS 30001 ranked best in ease of peeling (Figure 1), suggesting that the two parameters are directly proportional. Though this cannot be substantiated in this study since some varieties did not follow that trend, there is some plausibility of this correlation. **Akingbala *et al.* (2005)** observed that ease of peeling and pulp-to-peel ratios both decreased during storage of cassava roots. This was attributed to loss of moisture which caused shrinkage of the root, thereby making the peel adhere more tightly to the pulp. Ease of peeling, as well as pulp-to-peel ratio is a critical determinant in the selection of cassava variety.

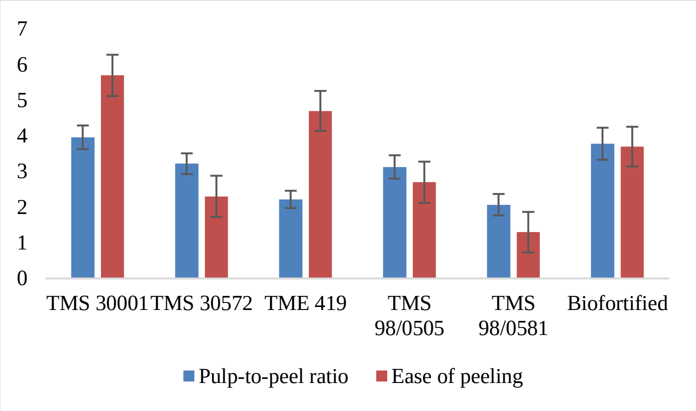

Figure 1 Pulp-to-peel ratio and ease of peeling of roots of six cassava varieties
Error bars indicate S.D. of triplicate determinations

Chemical properties of six cassava varieties

The cassava varieties varied from 64.01% to 77.38% in moisture contents (Table 2). The lowest moisture contents obtained for TMS 30572 and TMS 98/0505 means relatively higher dry matters (approximately 34 and 36%, respectively). This indicates higher yield of *gari*, hence higher profitability for *gari* producers **(Bentley *et al.*, 2017)**. Furthermore, cassava generally has a very short life, and varieties with higher moisture contents are even more prone to microbial spoilage **(Richardson, 2013)**, hence those with lower moisture contents are preferred for better post-harvest storage and physiological stability. **Akingbala *et al.* (2005)** previously reported 67 g/kg (67%) for freshly harvested TMS 30572, which is similar to the value obtained for same variety in this study. **Richardson (2013)** reported 56.50 – 68.80% as the moisture contents of five different cassava varieties studied.

The starch contents of TMS 98/0581 and biofortified cassava varieties were quite similar (34.53% and 34.03%, respectively) and were significantly lower than those of other varieties (56.19 – 61.94%) (Table 2). The difference in starch contents of the various cassava roots can be attributed to varietal difference **(Agiriga and Iwe, 2016)**. Age and geneotipic differences can also contribute to variation in starch contents. This is plausible since these factors can influence some of the enzymes responsible for starch synthesis **(Ayetigbo *et al.*, 2018)**. Similar to the findings from this study, a research on three different varieties of cassava revealed that TMS 30572 and TME 419 both had higher starch contents than TME 98/0505 **(Agiriga and Iwe, 2016)**. Starch yield is a very critical parameter in the overall yield potential and dry matter of cassava crop **(Agele *et al.*, 2018)**. While *gari* is the major product of cassava in Africa, the most versatile and valuable product is starch **(Ladeira *et al.*, 2013)**. The values of starch recorded here are lower than the range of values (68.30 - 76.94) reported by **Ladeira *et al.* (2013)**. However, **Ikegwu *et al.* (2009)** noted 48.25 – 52.05% as the starch contents of 13 improved cassava cultivars studied, which are within the values obtained in this study.

Table 2 Chemical compositions of six cassava varieties

Samples	Moisture (%)	Starch (%)	Hydrogen Cyanide (mg/kg)
TMS 30001	70.67^{c} ± 0.15	31.47^{e} ± 0.03	47.76^{b} ± 0.07
TMS 30572	66.07^{d} ± 0.48	61.94^{a} ± 0.24	44.60^{bc} ± 3.46
TME 419	70.83^{c} ± 0.13	56.19^{c} ± 0.12	43.70^{c} ± 0.07
TMS 98/0505	64.01^{e} ± 0.17	59.56^{b} ± 0.41	46.20^{bc} ± 0.07
TMS 98/0581	77.38^{a} ± 0.13	34.53^{d} ± 0.62	40.52^{e} ± 0.07
Biofortified	74.41^{b} ± 0.15	34.03 ± 0.10	58.86^{a} ± 2.43

Note: Mean ± S.D. Mean values with different superscripts along the same column differ significantly (p≤0.05)

Values ranging from 40.52% to 58.86 mg/kg were obtained as the hydrogen cyanide contents of the studied cassava roots, with biofortified cassava variety recording the highest value while TMS 98/0581 recorded the lowest (Table 2). According to the classification of **Uchendu *et al.* (2013)**, all the varieties can be classified as being low (below 50 mg/kg) in cyanide level, except the biofortified variety which is intermediate (50 – 100 mg/kg). They can also be classified as non-toxic and moderately toxic, respectively **(Fasuyi and Aletor, 2005)**. Implication of this is that the biofortified cassava variety requires more processing for detoxification than other varieties in this study. **Eleazu and Eleazu (2012)** previously reported that yellow cassava varieties studied contained higher amount of hydrogen cyanide than their white counterparts, including TMS 98/0505. The authors hypothesised that the bitter taste that some researchers **(Iglesias *et al.*, 1997)** have reported in yellow cassava might not be unconnected with their cyanogenic content. Though the link between cyanide and bitterness has not been convincingly documented in literature, the report by an Indian researcher that cyanide was acrid in taste is a clue to this plausibility **(Eleazu and Eleazu, 2012)**. The hydrogen cyanide contents recorded for other varieties in this study agree with the report of **Agele *et al.* (2018)** who described TMS 98/0505, TMS 98/0581, TMS 30572 and TME 419 as being low in hydrogen cyanide, and were recommended for domestic use.

Percentage yield (%) of *gari* from six cassava varieties

Gari yields varied among the cassava varieties from 10.11% for TMS 98/0581 to 20.11% for TMS 30001 (Table 3). The more the *gari* yield potential of a cassava variety, the more its commercial value and demand by *gari* producers. The percentage yields in this study are lower than some figures (28.0 – 37.0%) available in literature (**Akingbala *et al.*, 2005; Karim *et al.*, 2009; Komolafe and Arawande, 2010; Oyeyinka *et al.*, 2019**). A number of factors could be responsible for this; for example, the moisture contents of the *gari* reported by the authors were within the range of 9.77 – 12.30% while the range of 5.61 – 8.73% was reported in this study. The difference might have resulted from moisture difference of the various cassava roots (**Karim *et al.*, 2009)**, as well as difference in ease of peeling and pulp-to-peel ratio (**Akingbala *et al.*, 2005)**. Furthermore, values in the range of 15 – 20% have also been reported as *gari* yields in some studies **(Karim *et al.*, 2016).**

Physical attributes of *gari* produced from six cassava varieties

Insignificant (p>0.05) variations were found in the lightness (L*) of *gari* samples from TMS 30001, TMS 30572, TME 419 and TMS 98/0581 (Table 3). However, these aforementioned samples were significantly (p≤0.05) lighter (whiter) in colour than those from TME 98/0505 and biofortified cassava varieties. *Gari* sample from TMS 30001 had the highest 'L*' value (74.18) while *gari* sample from TMS 98/0581 had the least (66.06). **Oyeyinka *et al.* (2019)** previously reported 68.68 using the same length of fermentation period as used in this study while values as high as 82.5 – 92.3% were earlier found when the effect of microwave energy and different drying periods were investigated **(Oduro and Clarke, 1999)**. This suugests that in addition to varietal difference, production method can influence the lightness of *gari*. Biofortified cassava *gari*, as expected, was significantly more yellowish with a 'b*' value of 26.27 when compared to other samples (18.20 – 19.11) (Table 3). This shows that instead of the use of palm oil for the production of *gari* for the desired yellow effect, biofortified cassava variety can be adopted. Though it has been reported that provitamin A is prone to loss during processing, the significant difference particularly in the 'b*' value suggests there is still a significantly higher amount of provitamin A in the biofortified cassava *gari* than in samples from other varieties. *Gari* samples from the various white cassava varieties had b* values within the recommeded range of 17 – 21 by Codex Alimentarius **(Oduro and Clarke, 1999).**

The *gari* samples significantly (p≤0.05) differred in particle size distributions (Table 3). Samples from TMS 98/0505 and biofortified cassava varieties had highest and lowest values of less than 1 mm (corresponding to fine particle size), respectively. The wide variance in the particle size of the *gari* samples might have varying influences on other properties, such as appearance **(Oluwamukomi and Jolayemi, 2012)** and functional properties **(Karim *et al.*, 2016).**

Difference in rate of fermentation due to possible variations in the amounts of fermentable sugars in the cassava roots might account for the observed variation in particle size. **Oduro *et al.* (2000)** previously highlighted extent of fermentation and roasting as some of the factors influencing particle size distribution of *gari*. The significant (p≤0.05) differences in pH recorded in this study corroborate this hypothesis. Difference in levels of starch damage during processing may also account for the observed variation as extent of starch damage has been postulated to result in different particle size distributions in *gari* samples **(Oyeyinka *et al.*, 2019)**. In addition to physical, functional and chemical properties, consumers' acceptance of *gari* is also partly determined by its particle size.

In terms of angle of repose, significant (p≤0.05) differences were also demonstrated by the *gari* samples (Table 3). These were in the range of 10.32 ^{o} for *gari* produced from TMS 98/0505 and 34.10^o for the sample from TME 419. Implication of this is that *gari* samples from the different cassava varieties would have different engineering properties including flowability and machine design requirements**. Edward (2001)** established the relationship between angle of repose and flow properties of particulate materials, noting that while angle of repose of less than 25^o corresponds to excellent flow, any value above 40^o denotes poor flow. It can thus be deduced that all the *gari* samples have good flow property, but samples from TMS 98/0505 is excellent in this respect. Correlation between smoothness, stickiness as well as roundness of *gari* with its angle of repose has also been established **(Oluwamukomi and Jolayemi, 2012)**. Angle of repose of *gari* is one engineering property that is seldom examined and documented in literature, probably due to the fact that mechanised handling of *gari* such as with the use of hopper is not yet popular. Meanwhile, **Oluwamukomi and Jolayemi (2012),** as well as **Karim *et al.* (2016)** earlier reported angle of repose of about 29^o for *gari* samples studied.

Table 3 Physical attributes of *gari* produced from six cassava varieties

Samples	Yield (%)	Colour			Particle size						Angle of repose (^{o})
		L^*	a^*	b^*	1 mm	1.4 mm	1.8 mm	3 mm	4 mm	Fine particles	
TMS 30001	20.11^a±0.16	74.18^a±1.70	8.67^{bc}±0.14	19.11^b±0.07	0.75^f	6.56^f	20.08^e	50.87^b	17.74^b	3.99^c	32.52^c±0.07
TMS 30572	17.14^b±0.09	71.86^{ab}1.94	8.91^{bc}±0.07	19.19^b±0.18	1.65^c	6.67^e	21.81^c	53.66^a	12.14^d	4.09^b	32.57^b±0.02
TME 419	16.16^c±0.12	72.09^{ab}±0.96	9.08^b±0.18	19.47^b±0.67	1.39^d	8.42^c	27.59^b	49.81^c	10.71^e	2.11^e	34.10^a±0.05
TMS 98/0505	17.02^b±0.11	71.14^b±2.37	8.90^{bc}±0.49	18.20^b±1.36	1.29^e	7.89^d	19.52^f	45.92.	18.66^a	6.75^a	10.32^a±0.02
TMS 98/0581	10.11^e±0.07	66.06^c±0.22	8.54^c±0.13	18.20^b±0.31	4.07^a	15.42^a	31.15^a	35.37^f	10.47^f	3.52^d	23.50^d±0.05
Biofortified	12.72^d±0.10	68.00^c±1.21	10.19^a±0.24	26.27^a±0.80	2.23^b	10.47^b	23.79	46.87^c	13.57^c	2.09^f	33.57^b±0.07

Note. Mean ± SD; Mean values with different superscripts along the same column differ significantly (p≤0.05).

Chemical properties of *gari* produced from six cassava varieties

The *gari* samples from the various cassava varieties significantly (p≤0.05) varied in moisture between 5.61 and 8.73 (Figure 2A). Moisture content is a very important parameter affecting the shelf stability of *gari*, with high moisture content predisposing the product to mould growth during storage **(Olanrewaju, 2016)**. Moisture content of *gari* also influences its water absorption and swelling capacities during soaking and reconstitution into dough (*eba*). All the *gari* samples are not above the 'not more than 10% level' stipulated in the reviewed quality standards of *gari* by Standard Organisation of Nigeria/International Institute of Tropical Agriculture (SON/IITA) **(Sanni *et al.*, 2005)**. The observed variations in the moisture contents of the *gari* samples did not correspond with those of the cassava roots. This suggests that the moisture content of a cassava root may not reliably determine the moisture content of *gari* made from it. Age of the roots at optimum maturity, as well as unique structural properties, differently affecting ease of dewatering, may partly explain the difference in moisture contents of the *gari* samples. Earlier studies highlighted age of cassava root, processing methods, and extent of dewatering and roasting as some of the factors affecting the moisture content of *gari* **(Abass *et al*., 2012; Apea-Bah, 2003)**.

Significant (p≤0.05) varietal differences were observed in the pH values of the *gari* samples (Figure 2B). While *gari* sample from TME 419 recorded the lowest value (4.44), sample from TMS 98/0581 had the highest (4.83). These values indicate accumulation of acidic compounds over a 5-day fermentation period and the variations may be attributed to different levels of fermentable sugars in the various roots. During fermentation of cassava roots, microorganisms such as *Corynebacterium manihot* and *Geotrichum candida* degrade the complex and simple carbohydrates, respectively, producing lactic and formic acids, thus causing a drop in pH. These values are not in variance with the 4.75 reported by **Karim *et al.* (2016)** but are relatively higher when compared with the range (3.42 – 3.84) documented by **Oyeyinka *et al.* (2019)**. Low pH brought about by fermentation helps to facilitate cyanide reduction in cassava root. It is also important from the sensory and storage quality stand points. Total titratable acidity (TTA) of the *gari* samples varied from 0.93 to 1.41% (Figure 2C). The significant (p≤0.05) differences observed in TTA of the various g*ari* samples can be attributed to varietal difference of cassava roots used.

TTA is a representation of organic acids released by lactic acid bacteria while fermenting cassava mash, and it has implication on the sensory and keeping quality of *gari* samples. The TTA values are not as high as those found by **Karim *et al.* (2016)**. **Achinewhu *et al.* (1998)** however also reported lower values between 0.85 and 0.99% for *gari* made from six cassava varieties, further indicating effect of varietal differences of cassava on the level of acidity developed during fermentation. Length of fermentation is another factor that contributes to variation in TTA of *gari* samples.

The *gari* samples had significantly (p≤0.05) different amounts of hydrogen cyanide, ranging from 8.65 mg/kg to 10.22 mg/kg (Figure 2D). All the samples, except *gari* from TMS 98/0581, comply with the 10 mg/kg safe limit recommended by World Health Organization. This was not expected as the root of TMS 98/0581 had the least hydrogen cyanide content. However, it also had the highest moisture content, suggesting that the value was low due to dilution effect of the high moisture content, since the analysis was on wet basis. Also, the hydrogen cyanide of *gari* from biofortified cassava did not correspond with the amount in the root, prior to processing. It is however probable that more cyanide volatilization due to roasting was responsible for this observation. This can be inferred from the higher reduction in the moisture content (92.3%) of biofortified cassava as compared to other varieties (87.17 – 91.74%). Difference in the amounts of fibrousness of the roots may also partly account for the variation in cyanide reduction, as TMS 98/0505 which had the least fibre content (results not shown) gave *gari* sample with the lowest hydrogen cyanide. It can thus be hypothesized that the lower the fibre content of cassava root, the easier its tissue disintegration and dewatering, and consequently, the higher will be cyanide reduction. Values as low as 4.21 – 6.49 mg/kg were noted by **Oyeyinka *et al.* (2019)**. Meanwhile, **Akingbala *et al.* (2005)** also reported values as high as 0.011 – 0.0152 g/kg (11.0 – 15.2 mg/kg).

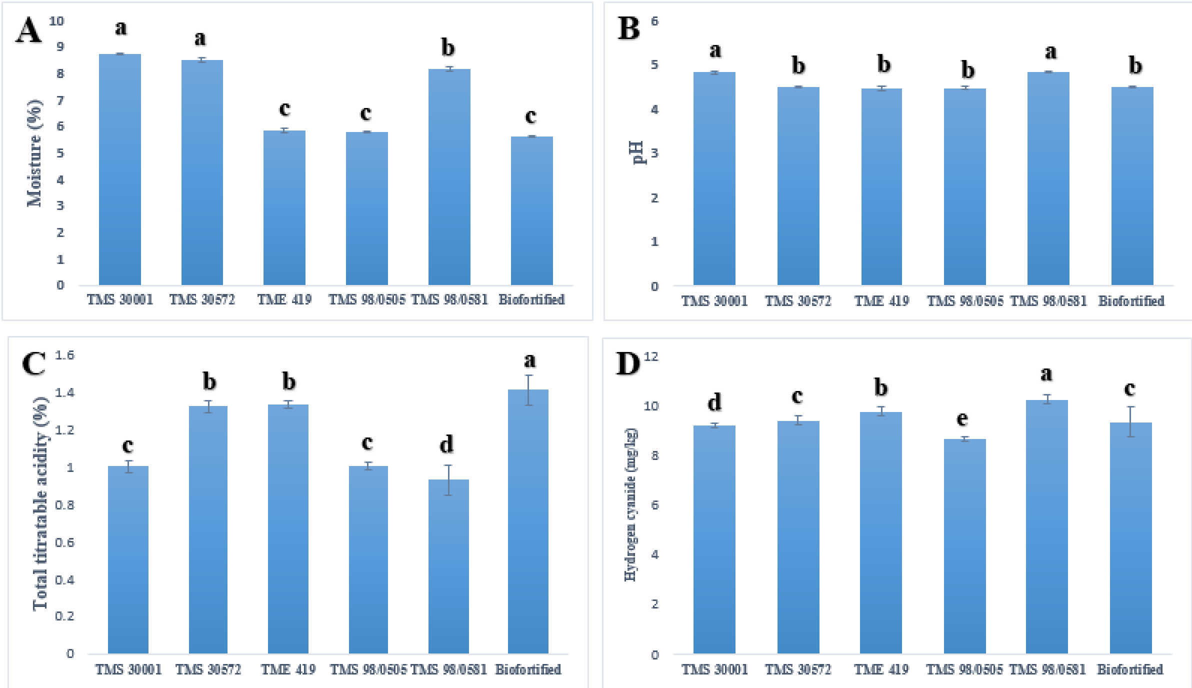

Figure 2 Chemical properties of *gari* from six cassava varieties
A= Moisture, B = pH, C = Total titratable acidity, D = Hydrogen cyanide
Error bars indicate S.D. of triplicate determinations**;** bars not followed by the same letter represent significantly (p≤0.05) different means

Sensory properties of *gari* produced from six cassava varieties

Some of the *gari* samples were at significant (p≤0.05) variance with regards to sensory characteristics (Table 4). *Gari* from TMS 30001 variety generally recorded the highest mean scores in all the sensory attributes, but only in colour was it significantly more preferred than every other sample. Sample from TMS 98/0505 for example had significantly similar mean score in other sensory attributes. The higher preference in colour for *gari* from TMS 30001 correlates with the objective colour analysis where the sample also recorded highest *'L*'* value (Table 3). Colour is a vital attribute in the assessment of *gari*, as the product is believed to be creamy white or white in colour. However, there was no substantial contrast between *gari* samples from TMS 30001 and TMS 98/0505 in overall acceptability, implying that colour is not the only determinant of consumers' choice for dry *gari*. Lower pH of *gari* from TMS 98/0505 (4.74) than sample from TMS 30001 (4.82) (Figure 2B) probably conferred on it more desired sourness than the latter.
Results of Principal Component Analysis (PCA) shows that all the sensory parameters highly contributed to the variation (67.5%) in the dry (Figure 3) *gari* samples, with overall acceptability being the most influential, while taste, colour, aroma, graininess and texture had relatively similar influence, in that order (Table 5). PCA is a useful tool in predetermining the main components of a food material whcih contribute to the major variations observed in its property. These PCA results can, therefore, inform the major sensory components to be characterised when developing products from the cassava varieties. Previously, in order to characterise the chemical attributes of tapioca grits from different cassava varieties, the major chemical components of importance were identified using the same method (Adebowale *et al.*, 2008).

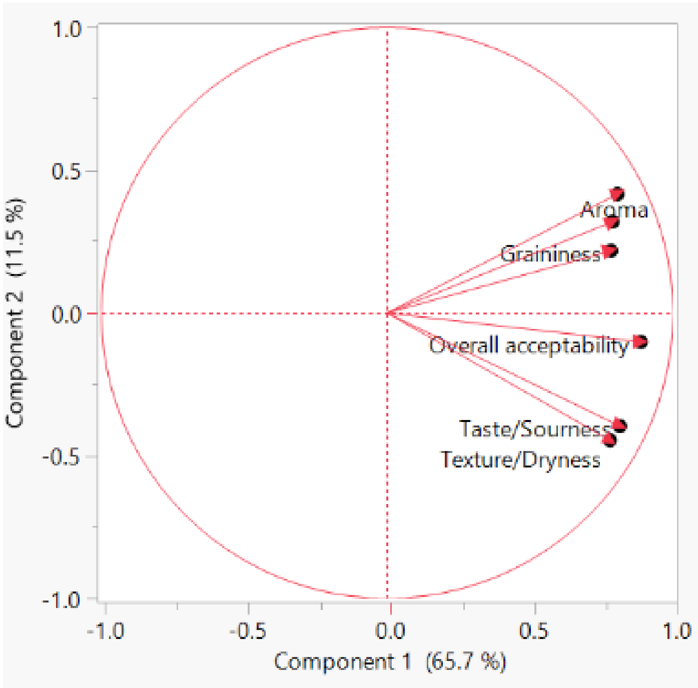

Figure 3 Principal Component Analysis of *gari* produced from six cassava varieties

Table 4 Sensory properties of *gari* produced from six cassava varieties

Samples	Colour	Aroma	Graininess	Taste/sourness	Texture	Overall acceptability
TMS 30001	$6.32^{a} \pm 0.76$	$5.54^{a} \pm 1.05$	$5.78^{a} \pm 1.22$	$5.22^{a} \pm 1.27$	$5.68^{a} \pm 1.28$	$6.00^{a} \pm 0.94$
TMS 30572	$5.58^{b} \pm 1.23$	$5.26^{a} \pm 1.14$	$5.24^{b} \pm 1.27$	$5.10^{a} \pm 1.57$	$5.46^{a} \pm 1.23$	$5.38^{b} \pm 1.12$
TME 419	$5.33^{b} \pm 1.47$	$4.77^{c} \pm 1.39$	$4.80^{b} \pm 1.53$	$5.31^{a} \pm 1.22$	$5.33^{a} \pm 1.32$	$5.23^{b} \pm 1.31$
TMS 98/0505	$5.41^{b} \pm 1.04$	$5.44^{ab} \pm 0.91$	$5.36^{ab} \pm 1.06$	$5.51^{a} \pm 1.14$	$5.56^{a} \pm 1.43$	$5.64^{ab} \pm 1.01$
TMS 98/0581	$3.36^{c} \pm 1.48$	$3.15^{d} \pm 1.70$	$3.77^{c} \pm 1.61$	$4.39^{b} \pm 1.79$	$4.62^{c} \pm 1.48$	$3.90^{c} \pm 1.55$
Biofortified	$4.77^{c} \pm 1.53$	$5.08^{bc} \pm 1.55$	$5.03^{b} \pm 1.39$	$5.08^{a} \pm 1.04$	$5.26^{a} \pm 1.35$	$5.31^{b} \pm 1.15$

Note. Mean ± SD; Mean values with different superscripts along the same column differ significantly (p≤0.05)

Table 5 Component matrix of sensory properties of *gari* produced from six cassava varieties

Parameter	Component 1
Overall acceptability	0.89
Taste	0.81
Colour	0.81
Aroma	0.79
Graininess	0.78
Texture	0.78

Extraction Method: Principal Component Analysis

Relationship between some critical parameters of six cassava varieties and their *gari*

Root size of the cassava varieties negatively correlated, though not significantly, with their dry matter, starch content and *gari* yield (Table 6). Implication of this is that while the cassava varieties with big sizes would meet the preference of cassava producers, satisfying their commercial need, same varieties may not be accepted by *gari* producers who desire high product yield. This finding is consistent with the report of **Achinewhu *et al.* (1998**) who stated that high yielding potential of cassava variety may not correspondingly translate to high *gari* yield and quality. *Gari* yield was however positively correlated with L^* value (lightness) ($p \leq 0.01$; $p \leq 0.05$), particle size ($p \leq 0.01$; $p \leq 0.05$) and overall acceptability ($p \leq 0.05$) of the *gari* samples in their particulate form. This suggests that attempts to improve on *gari* yield from cassava may not have negative effect on final quality. But since root size negatively correlates with *gari* yield, genetic improvement on the root size of cassava may have negative effects on the final quality of *gari*. **Assfaw *et al.* (2017)** earlier reported that genetic improvement of cassava may have influence on the quality of its final product, and that this will in turn determine consumers' acceptance of such variety.

Table 6 Relationship between critical parameters of cassava root and *gari* qualities

		RS	DM	STARCH	EP	PTPR	Yield	L	PS	OAG
RS	Pearson Correlation	1	-0.29	-0.24	0.57	0.37	-0.09	-0.03	-0.13	0.24
	Sig. (2-tailed)		0.57	0.65	0.23	0.47	0.86	0.95	0.81	0.65
DM	Pearson Correlation		1	0.79	-0.03	0.27	0.72	0.67	-0.80	0.68
	Sig. (2-tailed)			0.06	0.96	0.60	0.11	0.15	0.06	0.14
STARCH	Pearson Correlation			1	-0.26	-0.28	0.32	0.35	-0.48	0.22
	Sig. (2-tailed)				0.62	0.60	0.54	0.50	0.34	0.68
EP	Pearson Correlation				1	0.40	0.52	0.59	-0.49	0.63
	Sig. (2-tailed)					0.43	0.29	0.22	0.33	0.19
PTPR	Pearson Correlation					1	0.53	0.42	-0.57	0.76
	Sig. (2-tailed)						0.29	0.41	0.24	0.08
Yield	Pearson Correlation						1	0.98**	-0.94**	0.89*
	Sig. (2-tailed)							.000	0.01	0.01
*L**	Pearson Correlation							1	-.925**	0.85*
	Sig. (2-tailed)								0.01	0.03
PS	Pearson Correlation								1	-0.93**
	Sig. (2-tailed)									0.01
	Sig. (2-tailed)									0.55
OAG	Pearson Correlation									1
	Sig. (2-tailed)									

Note: RS= Root size; DM = Dry matter; EP= Ease of peeling; PTPR = Pulp to peel ratio; L^* = Lightness, PS = Particle size; OAG = Overall acceptability of *gari;* ** = significant at the 0.01 level (2-tailed); * = significant at the 0.05 level (2-tailed)

CONCLUSION

Biofortified cassava variety in this study was the best in root size while TMS 98/0505 had the highest dry matter. Biofortified cassava variety contained moderately toxic cyanide potential but this was easily detoxified to within safe limit during processing. Generally, cassava varieties with higher dry matters gave higher *gari* yield but the influence was in interaction with corresponding pulp-to-peel ratios; TMS 30001 had the highest *gari* yield. All the *gari* samples had good physical properties, except that from TMS 98/0581 which was least in whiteness (L^* value). *Gari* sample from TMS 98/0505 showed the highest flow property required for design of hopper for mechanized handling. The moisture level of the *gari*, irrespectieve of cassava variety, did not exceed the 12% maximum recommended for particulate food materials; but *gari* from TMS 98/0581 had residual cyanide content above the less than 10 mg/kg safe limit recommended by World Health Organisation. *Gari* from TMS 30001 generally had the highest sensory ratings but was not significantly better than sample from TMS 98/0505 in overall acceptability. It was revealed from the study that root size negatively correlated with root dry matter, starch content and *gari* yield.

There is the need for cassava breeders to review their research objectives in such a way that the preferences of cassava producers, *gari* producers and consumers are harmonized for use in their future development and screening of new cassava varieties.

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