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Can improved cassava genotypes from the breeding program substitute the adopted variety for *gari* production? Biophysical and textural attributes approach

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The use of the biophysical and textural attributes of *gari/eba* to determine the possible substitution of an adopted cassava variety (TMBE419) with the improved genotypes from the breeding program was evaluated in this study. Standard methods were used for the characterization of the biophysical and textural attributes of the *gari/eba* from different cassava roots. It was observed that the mean of the biophysical attributes of the *gari* is swelling power (SWP) 12.46%, dispersibility 59.70%, water absorption capacity (WAC) 474.60%, peak 355.82 RVU, breakdown 111.02 RVU, and final 423.07 RVU viscosities, peak time 4.91 min, pasting temperature 80.14°C, moisture content 3.92%, ash content 0.98%, starch content 71.98%, amylose content 31.47% and cyanogenic potential (CNP) content 0.47 mg HCN/kg. There were significant differences ($p < 0.05$) in all the biophysical attributes of the gari samples. The instrumental texture attribute of the *eba* is hardness 40.46 N/m^2, mouldability 0.93, and stretchability 1.04. The sensory texture attributes depict that all the *eba* was moderately soft, sticky, and mouldable. Significant differences ($p < 0.05$) exist in the instrumental and sensory texture attributes of the eba samples. The PCA shows that *gari* made from TMS14F1285P0006 and TMS13F1053P0010 genotypes may have similar behavior in terms of dispersibility, SWP, and peak and breakdown viscosities to that of the TMBE419 variety. Also, the stickiness of the *eba* prepared from the TMS14F1285P0006 and TMS13F1053P0010 genotypes may be the same as that of the TMBE419 variety. Therefore, TMS14F1285P0006 and TMS13F1053P0010 genotypes may be good replacements for producing *gari/eba* in place of the TMBE419 variety.

KEYWORDS

improved cassava genotype, *gari/eba*, quality attributes, varietal substitution, adopted cassava variety

Introduction

Varietal differences have played vital roles in the production of diverse food products such as *gari* and have meaningfully impacted the quality characteristics of the product. Hence, income, food security, culinary, and agronomic needs are not the only factors considered for the selection of cassava varieties by the producers, but also the preservation of their cultural uniqueness while adopting both the improved genotypes introduced by breeders and the high-yielding landraces suitable for different value-added products (Awoyale et al., 2022). The information on the aptness of cassava varieties for vastly required products like *gari* will contribute to providing solutions on how to balance the needs of farmers with those of the end-users in terms of their chosen qualities in the breeding programs (Abass et al., 2022). This was corroborated by Thiele et al. (2021) and Abass et al. (2022). These researchers confirmed that inadequate precedence given to consumer-preferred traits by breeding programs backs the partial uptake of improved genotypes and their low varietal turnover for *gari* production.

Gari is a roasted, fermented cassava grit, consumed raw, soaked in cold water, or reconstituted in hot water into *eba*, and common in the diets of millions of people in developing countries (Abass et al., 2022). Awoyale et al. (2020) reported that varieties and the interactions between varieties and locations had a significant effect on the biophysical attributes (except pasting temperature and ash content) of the *gari*. Abass et al. (2022) on their part added that high product yield, high starch content, high solubility index, high peak viscosity and low setback viscosity are likely biophysical attributes that could be used as criteria for predicting *gari* quality and variety adoption by cassava processors. Textural attribute, which is the sensory and functional manifestation of the rheological and biophysical attributes of foods has also been considered a very important quality index for *eba* (Awoyale et al., 2021a). Awoyale et al. (2021a) stated that a significant and negative correlation exists between the mouldability of the eba and the sugar and amylose contents of *gari*. The stretchability of the eba had a significant negative correlation with the bulk density and a significant positive correlation with the setback viscosity of the *gari*. A significant and negative correlation exists between the stickiness of the eba and the amylose contents of the *gari*.

Of all the adopted cassava varieties, TME 419 otherwise known as TMBE419 used in this study has been widely adopted to produce *gari* due to its high product yield and good biophysical attributes among others (Udensi et al., 2011; Teeken et al., 2018; Abass et al., 2022). Therefore, the use of the biophysical and textural attributes of *gari/eba* to determine the possible substitution of an adopted cassava variety (TMBE419) with the improved genotypes from the breeding program was evaluated.

Materials and methods

Materials

Twenty-nine (29) improved cassava varieties with one control (TMBE419 variety) (Table 1) were harvested from the Ikenne demonstration farm of the International Institute of Tropical Agriculture (IITA), Ogun State, Nigeria. Approximately 20 kg of the varieties were used for *gari* production. The TMBE419 variety also known as TME419 or *Idileruwa* was used as a control variety because it has been established to be very good and well adapted for *gari* production by researchers (Agele et al., 2018; Oyeyinka et al., 2020; Dimkpa and Theophilus, 2021; Abass et al., 2022).

Methods

Gari production

The traditional spontaneously fermented method was used to produce the *gari*, where the peeled, washed, and grated mash was fermented for about four (4) days before bagging, dewatering, granulating, and sieving, roasting, cooling, and packaging (Awoyale et al., 2020).

Functional properties

Bulk density

The standard methods described by Ashraf et al. (2012) were used for the determination of bulk density. About 10 g of the *gari* sample was weighed into a 50 ml measuring cylinder. The measuring cylinder containing the sample was lightly tapped 10 times on the laboratory workbench to achieve a constant height. The result was expressed as g/ml, which is the bulk density.

Swelling power and solubility index

A 2.5% aqueous dispersion of *gari* was put in centrifuge tubes, covered to prevent spilling, and subjected to heat in a shaker water bath (Precision Scientific, Model 25: Chicago, USA) at 85°C for 30 min (Afoakwa et al., 2012). The centrifuge tubes were then cooled to ambient temperature and centrifugated at 3,000 x g for 15 min, using the Thelco GLC-1, 60647 centrifuges (Chicago, USA). The precipitate separated from the supernatant was weighed, after which the supernatant was evapourated in a hot air oven (Memmert GmbH+Co.KG: D-91126, Germany) at 105°C, and the residue was weighed. Equations (1) and (2) were used for the calculation of the swelling power (SWP) and solubility index respectively.

$$SWP = \frac{wt\ of\ precipitated\ paste}{wt\ of\ sample} - wt\ of\ residue\ in\ supernatant \times 10 \quad (1)$$

$$SI = \frac{Wt\ of\ residue\ in\ supernatant}{Wt\ of\ sample} \times 100 \quad (2)$$

TABLE 1 Improved cassava genotypes and the control variety used to produce *gari/eba*.

S/No	Cassava varieties
1	IBA30572
2	IBA98051
3	IITA-TMS-IBA30572
4	IITA-TMS-IBA980581
5	TMEB419 (Control)
6	TMS13F1049P0001
7	TMS13F1053P0010
8	TMS13F1053P0015
9	TMS13F1088P0007
10	TMS13F1153P0001
11	TMS13F1160P0004
12	TMS13F1160P0005
13	TMS13F1307P0016
14	TMS13F1343P0004
15	TMS13F1343P0022
16	TMS13F2110P0008
17	TMS14F1016P0006
18	TMS14F1035P0004
19	TMS14F1035P0005
20	TMS14F1195P0005
21	TMS14F1285P0006
22	TMS14F1285P0017
23	TMS14F1287P0008
24	TMS15F1041P0003
25	TMS15F1302P0020
26	TMS15F1466P0195
27	TMS15F1467P0011
28	TMS15F1482P0098
29	TMS16F2003P0029
30	TMS16F2006P0038

Water absorption capacity

The *gari* water absorption capacity (WAC) was determined by weighing 1 g into a clean pre-weighed dried centrifuge tube and mixed adequately with distilled water (10 ml) by vortexing, after which the suspension was allowed to stand for 30 min and centrifuged (Thelco GLC- 1, 60647: Chicago, USA) at 3,500 rpm for 30 min. The supernatant was decanted after centrifugation, with the tube and the sediment weighed. The weight of water (g) retained in the sample was then reported as WAC (Oyeyinka et al., 2013).

Dispersibility

The *gari* dispersibility was determined by weighing 10 g of the sample into a 100 ml measuring cylinder, after which distilled water was added up to the 50 ml mark of the measuring cylinder. The *gari* and distilled water mixture were stirred vigorously using a spatula and allowed to settle for 3 h. The volume of settled particles in the measuring cylinder was recorded, and the dispersibility was calculated using Equation (3).

$$\textit{Dispersibility}\ (\%) = \frac{(50 - \text{volume of the settled particle})}{50} \times 100 \tag{3}$$

Pasting properties

The *gari* pasting properties were determined using the method reported by Falade and Olugbuyi (2010). About 3.5 g of the sample was mixed with 25 ml of distilled water in a canister. The mixture was thoroughly stirred, and the canister was fitted into the Rapid Visco Analyser (Model RVA 4500, Perten Instrument, and Australia) equipped with a 1,000 cmg sensitivity cartridge. The slurry was heated inside the Rapid Visco Analyzer (RVA) from 50 to 95°C at a rate of 1.5°C/min as recommended, held at this temperature for 15 min, and cooled to 50°C. The pasting properties (peak viscosity, trough, breakdown, final viscosity setback, peak time, and pasting temperature) of the samples were displayed on the computer screen connected to the Thermocline for Windows Software of the RVA.

Chemical composition

Moisture content

The *gari* sample (3 g) was weighed into a pre-weighed dried moisture can. The can containing the sample was placed in a well-ventilated oven (Memmert GmbH+co.Kg, Oven model D-91126 Schwabach FRG, Germany) operated at 105 ± 2 °C for 16 h. The loss in weight was recorded and the moisture content (MC) was calculated using Equation (4) (AOAC, 2000).

$$\text{MC}\ (\%) = \frac{(\text{Weight of can} + \text{sample before drying}) - (\text{Weight of can} + \text{sample after drying})}{\textit{Weight of sample}} \times 100 \tag{4}$$

Ash content

The ash content of the sample (3 g) was determined by burning off moisture and all the organic constituents at 600°C for 6 h in a muffle furnace (Ney Vulvan$^{\text{TM}}$ furnace model 3-1750, USA) (AOAC, 2000). Then the weight of the residue after incineration and cooling was recorded, and the ash content was calculated using Equation (5).

$$\text{Ash content}\ (\%) = \frac{(\text{Weight of crucible} + \text{ash}) - (\text{Weight of crucible})}{\text{Weight of sample}} \times 100 \tag{5}$$

Starch and sugar contents

The sample (0.02 g) was weighed into a centrifuge tube with the addition of 1 ml ethanol, 2 ml distilled water, and 10 ml hot ethanol. The mixture of the sample, distilled water, and ethanol was vortexed and centrifuged (Thelco GLC- 1, 60647: Chicago, USA) at 2,000 rpm for 10 min. The supernatant was then decanted and used for the sugar content determination, and the starch content was estimated by hydrolyzing the sediment with perchloric acid. The color of the solution was developed using phenol and sulfuric acid reagents, while the standard glucose curve was used to estimate sugar. The absorbance of the developed color was read at 490 nm using a spectrophotometer (Genesys 10S UV-VIS, China) (Onitilo et al., 2007). The sugar and starch contents were calculated using Equations (6) and (7) respectively.

$$\%Sugar = \frac{(A-1) \times D.F \times V \times 100}{B \times W \times 10^6} \tag{6}$$

$$\%Starch = \frac{(A-1) \times D.F \times V \times 100 \times 0.9}{B \times W \times 10^6} \tag{7}$$

A = Sample absorbance.
I = Sample intercept.
D.F = Sample dilution factor, which depends on the aliquot taken for analysis.
V = Volume.
B = Standard curve slope.
W = Sample weight.

Cyanogenic potential

The milled *gari* sample (30 g) was properly homogenized with 250 ml of 0.1 M orthophosphoric acid and centrifuged (Thelco GLC- 1, 60647: Chicago, USA). The supernatant was taken as the extract after which 0.1 ml of linamarase enzyme was added to 0.6 ml of the extract. About 3.4 ml of the acetate buffer (pH 4.5) solution was added, stirred to mix and 0.2 ml of 0.5% chloramines-T and 0.6 ml of color reagent were added and allowed to stand for 15 min. for color development. The absorbance value was read at 605 nm using a spectrophotometer (Genesys 10S UV-VIS, China) against a blank. The blank contains all reagents but with the replacement of KCN with 0.1 ml phosphate buffer (Essers et al., 1993).

A standard curve and its slope (b) were obtained from the data generated from the standard solution by plotting absorbance values (Y-axis) against standard concentrations (X-axis). The unknown mean absorbance (A) and the weight of the sample (w) were used to calculate the residual cyanide, using Equation (8).

$$\textit{Residual cyanide}\ (\text{mg HCN/kg sample}) = \text{A}\times 250\times 0.4151\text{b}\times\text{w} \tag{8}$$

Preparation of *eba* for sensory and instrumental texture profile analysis

The *eba* was prepared from the *gari* samples produced from the 30 cassava varieties using the method described by Awoyale et al. (2022). This was done by continuously stirring the *gari* (100 g) and adding to boiled water (195 ml) to form a smooth dough. Fifteen (15) trained panelists from the staff and graduate students of the International Institute of Tropical Agriculture (IITA), Ibadan, who consumes *eba* regularly were used for the sensory texture profile analysis, after their verbal agreement. The attributes evaluated in the *eba* are mouldability, stretchability, stickiness, and hardness. The tenets of the Helsinki declaration of 1964 and approved by the International Institute of Tropical Agriculture review committee on ethics were followed in the sensory texture profiling.

A 50 kg load cell texture analyzer (TA-XTPlus-Stable Microsystems) was used for the instrumental texture profile analysis of the *eba*. The texture attributes obtained from the analyzer are hardness, adhesiveness, cohesiveness, stretchability, and gumminess of the *eba*. The *eba* samples were kept inside a cooler to maintain the temperature (28–30 °C) during the evaluation.

Statistical analysis

The XLSTAT (Trial Version 2021) software was used for the principal component analysis (PCA), while the Statistical Package for Social Sciences (SPSS version 21) software was used for the separation of means of the data generated.

Results and Discussion

Functional properties of gari

The functional properties of *gari* are known to affect the behavior during preparation for consumption (Awoyale et al., 2015). The average value of the functional properties of *gari* produced from the cassava varieties is swelling power (SWP) 12.46%, solubility index (SI) 7.14%, dispersibility 59.70%, bulk density (BD) 75%, and water absorption capacity (WAC) 474.60% (Table 2). There were significant differences ($p < 0.05$) in all the functional properties of the *gari* samples.

The degree of the interaction within the amorphous and crystalline domains between starch chains is influenced by the SWP and SI. Also, a good quality *gari* has been reported to swell to three times its original volume (Awoyale et al., 2020). The *gari* SWP ranged from 7.82–15.16%, with the TMS13F2110P0008 *gari* having the highest and TMS15F1482P0098 *gari* the least ($p < 0.05$). The SWP of the *gari* samples concurs with the results reported for *gari* of different varieties (Awoyale et al., 2020), but

TABLE 2 Functional properties of *gari* produced from the cassava genotypes and the control variety.

Cassava varieties	Swelling power (%)	Solubility index (%)	Dispersibility (%)	Bulk density (%)	Water absorption capacity (%)
TMS13F1049P0001	14.50 ± 1.03ab	12.16 ± 4.24a	66.00 ± 1.41c-f	55.00 ± 0.71e	459.42 ± 36.39e-j
TMS13F1053P0010	14.09 ± 0.16ab	6.72 ± 0.33e-h	62.50 ± 0.71f-h	72.50 ± 0.04ab	442.64 ± 11.26g-j
TMS13F1053P0015	14.42 ± 0.76ab	7.34 ± 0.14ef	62.50 ± 3.54f-h	72.50 ± 0.11ab	527.52 ± 4.60b-d
TMS13F1088P0007	14.43 ± 0.06ab	7.51 ± 0.58ef	67.50 ± 0.71b-e	72.50 ± 0.04ab	440.52 ± 27.73g-j
TMS13F1153P0001	14.55 ± 0.36ab	11.58 ± 0.30ab	71.00 ± 1.41ab	77.50 ± 0.11ab	543.81 ± 11.03bc
TMS13F1160P0005	14.28 ± 0.57ab	8.70 ± 0.11c-e	53.50 ± 2.12i-k	80.00 ± 0.00ab	503.93 ± 48.51c-e
TMS13F1160P0004	13.92 ± 0.30ab	7.69 ± 0.02d-f	61.00 ± 1.41gh	72.50 ± 0.04ab	530.89 ± 15.70bc
TMS13F1307P0016	14.16 ± 1.00ab	7.19 ± 0.01e-g	65.00 ± 1.41d-f	77.50 ± 0.04ab	472.80 ± 23.66e-h
TMS13F1343P0022	14.24 ± 0.06ab	7.00 ± 0.91e-g	67.00 ± 1.41c-e	70.00 ± 0.00cd	535.65 ± 43.75bc
TMS13F1343P0004	13.50 ± 0.51b	8.25 ± 0.77c-e	55.50 ± 0.71ij	60.00 ± 0.07de	496.23 ± 29.88c-f
TMS13F2110P0008	15.15 ± 0.02a	8.59 ± 0.07c-e	61.00 ± 0.00gh	77.50 ± 0.04ab	541.30 ± 43.82bc
TMS14F1016P0006	15.07 ± 0.23a	9.14 ± 0.36b-e	69.00 ± 5.66a-c	77.50 ± 0.04ab	600.06 ± 33.42a
TMS14F1035P0004	14.92 ± 0.15a	12.29 ± 2.23a	68.00 ± 0.00b-d	100.00 ± 0.00a	527.71 ± 1.58b-e
TMS14F1285P0006	14.36 ± 0.71ab	10.48 ± 1.03a-c	64.00 ± 0.00e-g	75.00 ± 0.07ab	431.07 ± 9.93g-j
TMS14F1285P0017	14.36 ± 0.22ab	10.63 ± 0.36a-c	56.50 ± 2.12i	80.00 ± 0.07ab	502.37 ± 26.34c-e
TMS14F1287P0008	14.91 ± 0.33a	5.21 ± 3.51f-j	72.00 ± 1.41a	75.00 ± 0.00ab	456.75 ± 5.22e-j
IBA30572	14.19 ± 0.06ab	7.29 ± 0.63ef	69.00 ± 1.41a-c	77.50 ± 0.04ab	478.86 ± 7.98d-g
IBA98051	14.77 ± 0.79ab	6.33 ± 0.35e-i	60.00 ± 1.41h	70.00 ± 0.00cd	556.37 ± 8.08ab
TMEB419 (Control)	14.60 ± 1.31ab	10.63 ± 0.52a-c	64.50 ± 0.71d-g	72.50 ± 0.04ab	447.49 ± 10.03f-j
TMS14F1195P0005	13.90 ± 0.05ab	10.30 ± 0.37a-d	71.00 ± 1.41ab	75.00 ± 0.00ab	444.25 ± 12.18f-j
TMS15F1467P0011	8.52 ± 0.46cd	3.93 ± 0.63ij	53.50 ± 2.12i-k	75.00 ± 0.07ab	418.95 ± 19.14i-k
TMS16F2006P0038	9.08 ± 0.41cd	4.20 ± 0.88h-j	52.00 ± 1.41j-l	72.50 ± 0.04ab	474.10 ± 12.39e-h
TMS16F2003P0029	9.32 ± 0.43c	3.70 ± 0.05ij	53.50 ± 2.12i-k	82.50 ± 0.04b	464.58 ± 7.84e-i
IITA-TMS-IBA30572	8.29 ± 0.30cd	4.46 ± 0.04g-j	53.50 ± 0.71i-k	75.00 ± 0.07ab	437.24 ± 6.99g-j
TMS15F1041P0003	8.59 ± 0.01cd	3.96 ± 0.16ij	47.00 ± 0.00m	75.00 ± 0.07ab	415.59 ± 13.52i-k
IITA-TMS-IBA980581	9.09 ± 0.25cd	3.39 ± 0.20j	50.00 ± 0.00k-m	70.00 ± 0.00cd	436.22 ± 9.04g-j
TMS15F1482P0098	7.82 ± 0.12d	3.89 ± 0.04ij	46.50 ± 0.71m	80.00 ± 0.00ab	375.95 ± 9.41k
TMS14F1035P0005	8.26 ± 1.19cd	4.89 ± 0.62f-j	49.00 ± 0.71lm	77.50 ± 0.04ab	440.35 ± 20.60g-j
TMS15F1302P0020	8.64 ± 0.05cd	3.55 ± 0.27ij	49.50 ± 0.71lm	77.50 ± 0.04ab	410.54 ± 5.19jk
TMS15F1466P0195	8.03 ± 0.37d	3.33 ± 0.49j	50.00 ± 0.00k-m	82.50 ± 0.04b	425.06 ± 21.67h-k
Mean	12.46	7.14	59.70	75.25	474.60
P level	***	***	***	***	***

Means with the same letters within the same column are not significantly different ($p < 0.05$); ***$p < 0.001$.
Values are means of duplicate analysis.

is higher compared to the values (3.13–5.30%) of gari samples produced from dried cassava chips (Udoro et al., 2014). This may be attributed to the treatment of chips during drying which may have resulted in the general weakening of the starch structure thus, lowering the swelling capabilities (Udoro et al., 2014). The SI of the *gari* was significantly lower in the TMS15F1466P0195 genotype (3.33%) and higher in that of the TMS14F1035P0004 genotype (12.29%) ($p < 0.05$). Thus, *gari* from the TMS15F1466P0195 genotype may consist of associated starch granules with a bulky and highly attached micellar structure because of its low SI (Awoyale et al., 2022). The result of the SI of *gari* from different varieties falls within the range of values of this study (Awoyale et al., 2020). Conversely, the SI of the gari samples (0.11–0.54%) reported by Udoro et al. (2014) was below the range of values in this study. The variation in the SI may be due to the cassava varieties and processing methods.

Higher dispersibility favors proper reconstitution of *gari* in hot water in the preparation of *eba* (Awoyale et al., 2022). The *gari* sample's dispersibility ranged between 46.50 and 72.00%, with the lowest value recorded in the TMS15F1482P0098 genotype and the highest in the TMS14F1287P0008 genotype, which was significantly different ($p < 0.05$). Thus, the TMS14F1287P0008 *gari* may be reconstituted in hot water, and without lumps, in the preparation of *eba* because of its high dispersibility. But it is imperative to add that the way the *gari* is added to the hot water during the preparation of *eba* might

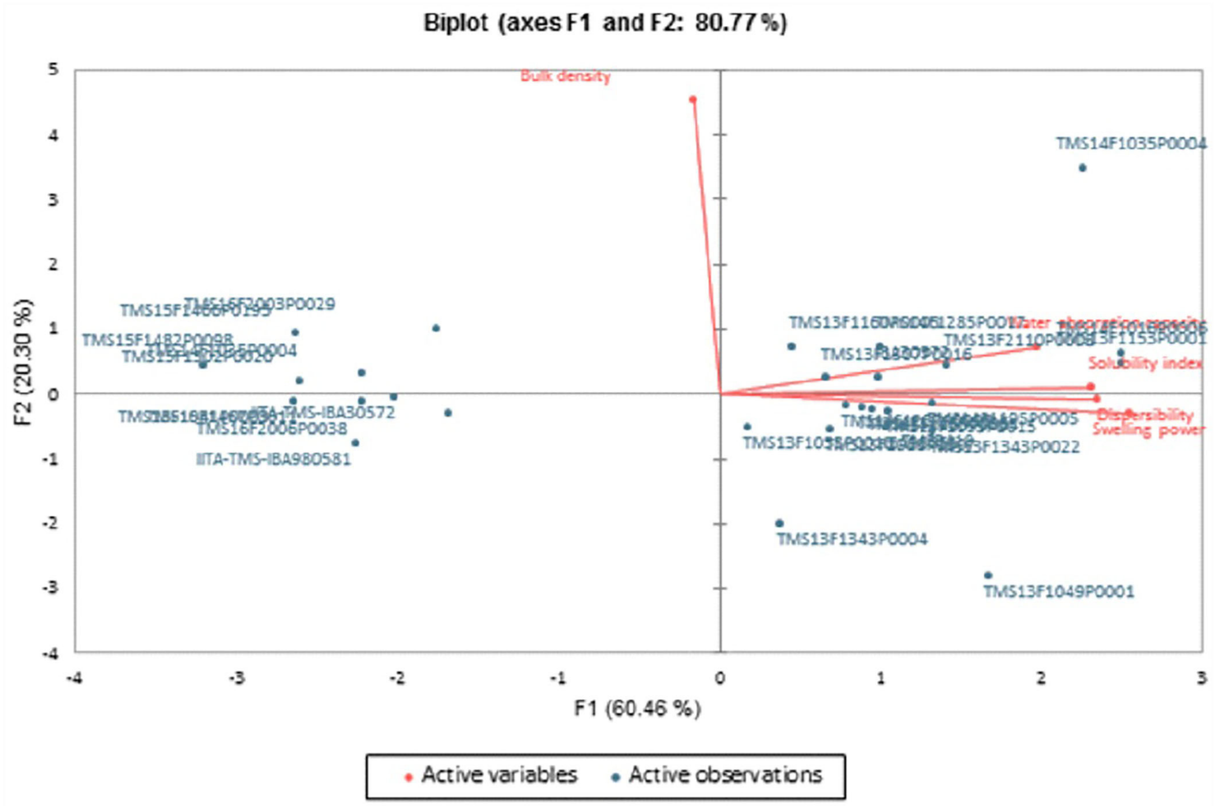

FIGURE 1
The principal component analysis biplot of the functional properties of *gari* samples.

influence the formation of lumps (Awoyale et al., 2020). Similar values (20.25–75.25%) were reported for the dispersibility of *gari* from different varieties (Awoyale et al., 2020).

Product with lower BD may occupy less space in a container, thus, the reduction in the packaging and transportation costs (Ikujenlola, 2014). Meaning that the TMS14F1035P0004 *gari* may occupy more space in a container because of its high BD (100%), while that of the TMS13F1049P0001 genotype may occupy less space due to its low BD (55%) ($p < 0.05$). The BD of *gari* reported for different cassava varieties (40–70%) by Awoyale et al. (2020) agrees with that of this study. The range of BD of gari samples (54–61%) produced in Lagos State falls within the values reported in this study (Sanni et al., 2008).

The *gari* produced from the TMS14F1016P0006 genotype (600.06%) might grip more water when prepared to *eba* because of its high WAC compared with that of the TMS15F1482P0098 genotype with lower values (375.95%) ($p < 0.05$) (Table 2). The range of values (413–541%) of the WAC for *gari* produced from different cassava varieties falls within that of the present study (Awoyale et al., 2020). Conversely, the values of the WAC reported in this study for the gari samples were higher than the 105% reported for *gari* by Owuamanam et al. (2010). The WAC of the gari samples (220–459%) stated by Udoro et al. (2014) partly agrees with that of this study. However, the variations in the WAC of all the samples may be attributed to the age and type of cassava variety, harvesting period, the time and temperature of roasting and the particle size of the gari (Owuamanam et al., 2010; Abass et al., 2012).

The PCA was applied to study the relationship between the functional properties of *gari* and different cassava genotypes to evaluate the possibilities of using them to produce *gari* instead of the TMBE419. The PCA biplot, as shown in Figure 1, allowed us to separate the cassava genotypes based on the functional properties of the *gari* samples. The result depicts a data variance of about 80.77%, with the PC1 and PC2 contributing 60.46 and 20.30% respectively. The PC1 was positively correlated with the SWP (r = 0.93), SI (r = 0.87), dispersibility (r = 0.89), and the WAC (r = 0.74) of the *gari* samples, while the PC2 had a positive correlation with the BD (r = 0.99) of the *gari* samples (Supplementary Table 1). The TMS14F1035P0004, IBA30572, TMS14F1285P0017, TMS13F1160P0005, TMS13F2110P0008, TMS14F1016P0006, TMS13F1153P0001, and TMS13F1307P0016 genotypes were in the same quadrant with the SI and the WAC of the *gari* samples. Similarly, TMS13F1053P0015, TMS13F1053P0010, TMS13F1343P0022, IBA98051, TMS14F1285P0006, TMS14F1287P0008,

TMS14F1195P0005, TMS13F1343P0004, TMS13F1160P0004, TMS13F1088P0007, and TMS13F1049P0001 genotypes and the TMEB419 variety were in the same quadrant with dispersibility and the SWP of the *gari* samples. Also, TMS16F2003P0029, TMS15F1482P0098, TMS15F1466P0195, TMS14F1035P0004, and TMS15F1302P0020 genotypes were in the same quadrant with the BD of the *gari* samples (Figure 1). Using TMEB419 as the control variety, *gari* of similar dispersibility and SWP may be produced from TMS13F1053P0015, TMS13F1053P0010, TMS13F1343P0022, IBA98051, TMS14F1285P0006, TMS14F1287P0008, TMS14F1195P0005, TMS13F1343P0004, TMS13F1160P0004, TMS13F1088P0007, and TMS13F1049P0001 genotypes since they belong to the same quadrants with these attributes.

Pasting properties of *gari*

Adebowale et al. (2008) reported that the pasting properties are important to predict the behavior of *gari* during and after cooking to *eba*. The mean of the pasting properties of the *gari* samples is peak viscosity 355.82 RVU, trough viscosity 244.81 RVU, breakdown viscosity 111.02 RVU, final viscosity 423.07 RVU, setback viscosity 178.26 RVU, peak time 4.91 min, and pasting temperature 80.14 °C (Table 3). Significant differences exist ($p < 0.05$) in the pasting properties of the *gari* samples.

The peak viscosity is the viscosity that backs the good texture of *eba*. Hence, the higher the peak viscosity, the firmer the texture of the *eba* (Ikegwu et al., 2009). This means that consumers who prefer the firm-textured *eba* may reconstitute the *gari* produced from the IBA98051 genotype (540.59 RVU) in boiled water because of its high peak viscosity. Also, those that prefer the soft textured *eba* may reconstitute *gari* from the IITA-TMS-IBA980581 genotype (220.63 RVU) in boiled water due to its low peak viscosity. Although, of importance is the fact that the texture of the *eba* may depend on the quantity of water used during reconstitution and the temperature and time spent for gelatinization (Newport Scientific, 1998). The peak viscosity of the *gari* produced using different periods of fermentation (283.92 RVU−366.92 RVU) falls within the range of values of the peak viscosity of the *gari* in this study (Awoyale et al., 2021a). The peak viscosity of the gari samples in this study was higher compared to some of the results (133. 50–324.25 RVU) reported by Olanrewaju and Idowu (2017) for gari samples. The variations in the peak viscosity of the gari samples may be attributed to varying degrees of garification (Olanrewaju and Idowu, 2017).

The ability of starch granules to remain undisrupted when the *gari* is subjected to a period of constant high temperature and mechanical shear stress is known as trough viscosity (Olatunde et al., 2017). The trough viscosity of the *gari* was lower in the TMS14F1287P0008 genotype (173.42 RVU) and higher in that of the TMS15F1466P0195 genotype (348.00 RVU). This depicts that *eba* produced from TMS15F1466P0195 *gari* may not withstand mechanical shear stress, and the starch granules may be disrupted because of their high trough viscosity, while that of the TMS14F1287P0008 *gari* may withstand mechanical shear stress (Olatunde et al., 2017). The range of values of the trough viscosity of the *gari* in this study agrees with the range of values (177.59 RVU−215.92 RVU) reported by Awoyale et al. (2021a) for the trough viscosity of *gari* from different periods of fermentation. The values reported for some of the trough viscosity of the *gari* produced from different particle sizes (70.92–239.17RVU) were lower compared to that of this study (Nwancho et al., 2014). The difference in the trough viscosity may be attributed to the varietal effect and the processing method used in the preparation of the *gari* samples.

The higher the breakdown viscosity, the lower the ability of the *gari* to withstand heating and shear stress during its reconstitution to *eba* (Adebowale et al., 2008; Awoyale et al., 2020). The breakdown viscosity of the *gari* ranged between 12.71 RVU and 241.79 RVU, with the IBA98051 genotype having the highest value and the IITA-TMS-IBA980581 genotype the lowest. This means that *eba* with undisrupted starch granule may also be produced from the IITA-TMS-IBA980581 *gari* due to its low breakdown viscosity compared to that of the IBA98051 variety with high breakdown viscosity. The value for the breakdown viscosity of *gari* from different periods of fermentation (97.38 RVU−151.00 RVU) falls within the range of values of the breakdown viscosity of this study (Awoyale et al., 2021a). Also, the breakdown viscosity of the gari samples (30.92–162.08 RVU) reported by Nwancho et al. (2014) was within the range of values of this study.

The final viscosity indicates the ability of the starchy material to form a gel after cooking (Sanni et al., 2006). Thus, the higher the final viscosity of the *gari*, the faster the gelatinization process when reconstituted in hot water to *eba*. *Gari* produced from the TMS14F1287P0008 genotype (268.58 RVU) had the lowest final viscosity and the TMS15F1466P0195 genotype the highest (632.50 RVU). Therefore, *gari* from the TMS15F1466P0195 genotype may gelatinize faster when reconstituted in boiled water to *eba* because of its high final viscosity, while that of the TMS14F1287P0008 genotype may gelatinize gently due to its low final viscosity (Sanni et al., 2006). The final viscosity values of *gari* produced from different periods of fermentation (322.25–337.55 RVU) (Awoyale et al., 2021a), and the *gari* produced from different cassava varieties (338.46–507.38 RVU) (Awoyale et al., 2020) was within the range of values compared to that of this study. On the contrary, the final viscosity (244.25 RVU) of *gari* samples reported by Oluwamukomi and Jolayemi (2012) was lower than that of the present study. The variation in the final viscosity of the *gari* may be due to differences in cassava varieties and processing methods.

When the setback viscosity during the cooling of the paste is low, it indicates greater resistance to syneresis/weeping of the starchy food (Awoyale et al., 2020). This infers that *eba* prepared

TABLE 3 Pasting properties of *gari* produced from the cassava genotypes and the control variety.

Cassava varieties	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting temperature (°C)
TMS13F1049P0001	331.04 ± 30.46f-m	205.00 ± 3.30h-j	126.04 ± 27.17b-f	321.34 ± 21.69l-n	116.33 ± 18.38gh	4.64 ± 0.05d-f	77.08 ± 0.53h
TMS13F1053P0010	462.67 ± 36.42b	251.84 ± 7.30d-g	210.84 ± 29.11a	379.25 ± 8.24g-l	127.42 ± 0.94f-h	4.47 ± 0.00f	77.93 ± 0.46gh
TMS13F1053P0015	321.38 ± 3.71g-m	230.67 ± 12.61e-i	90.71 ± 8.90e-k	380.63 ± 2.41g-l	149.96 ± 15.03d-g	5.04 ± 0.33c-e	81.58 ± 0.04b-d
TMS13F1088P0007	446.71 ± 7.95bc	224.05 ± 4.42f-i	222.67 ± 3.54a	362.88 ± 2.18i-m	138.84 ± 6.60e-g	4.57 ± 0.05ef	77.08 ± 0.46h
TMS13F1153P0001	292.09 ± 2.00k-m	197.55 ± 9.72h-j	94.54 ± 7.72e-k	334.25 ± 7.31k-m	136.71 ± 2.42e-g	4.60 ± 0.00d-f	77.75 ± 0.71h
TMS13F1160P0005	435.71 ± 40.01b-d	303.42 ± 32.88c	132.29 ± 7.13b-e	487.71 ± 2.65c-e	184.30 ± 30.23cd	5.44 ± 0.05bc	79.90 ± 1.20d-f
TMS13F1160P0004	357.54 ± 45.55e-k	270.59 ± 2.35c-e	86.96 ± 43.19f-k	439.13 ± 46.38e-g	168.55 ± 44.02d-f	5.40 ± 0.28bc	82.73 ± 0.67b
TMS13F1307P0016	302.42 ± 6.01j-m	193.42 ± 4.12h-j	109.00 ± 10.14c-h	347.09 ± 7.30j-m	153.67 ± 3.18d-g	4.74 ± 0.09d-f	81.95 ± 0.64bc
TMS13F1343P0022	354.67 ± 16.26e-k	238.63 ± 8.55e-h	116.04 ± 7.72b-f	387.63 ± 2.41f-k	149.00 ± 6.12d-g	4.64 ± 0.05d-f	79.53 ± 0.46e-g
TMS13F1343P0004	302.46 ± 3.36j-m	190.42 ± 6.60ij	112.04 ± 3.24c-g	316.88 ± 0.88l-n	126.46 ± 7.48f-h	4.73 ± 0.00d-f	80.73 ± 0.04c-e
TMS13F2110P0008	361.88 ± 5.48e-k	223.59 ± 0.59f-i	138.29 ± 4.90b-d	378.17 ± 10.25g-l	154.59 ± 9.67d-g	4.63 ± 0.14d-f	79.45 ± 0.64e-g
TMS14F1016P0006	374.13 ± 44.48d-i	232.50 ± 22.98-i	141.63 ± 21.50b-d	393.84 ± 9.07f-k	161.34 ± 13.91d-f	4.94 ± 0.19d-f	81.08 ± 0.53c-e
TMS14F1035P0004	272.54 ± 4.30mn	200.38 ± 8.31h-j	72.17 ± 4.01g-l	355.92 ± 5.42i-m	155.54 ± 2.89d-g	5.47 ± 0.09a-c	82.73 ± 0.67b
TMS14F1285P0006	363.84 ± 53.27e-j	233.79 ± 26.93e-i	130.05 ± 26.34b-f	371.54 ± 35.65h-m	137.75 ± 8.73e-g	4.70 ± 0.14d-f	80.30 ± 0.64c-f
TMS14F1285P0017	416.42 ± 49.26b-e	258.38 ± 34.71c-f	158.04 ± 14.55b	418.67 ± 24.87f-i	160.29 ± 9.84d-f	4.50 ± 0.04f	80.30 ± 0.57c-f
TMS14F1287P0008	304.75 ± 8.24i-m	173.42 ± 6.13j	131.33 ± 2.12b-e	268.58 ± 10.61n	95.17 ± 4.48h	4.50 ± 0.24f	77.83 ± 0.53h
IBA30572	307.71 ± 35.53h-m	202.21 ± 21.39h-j	105.50 ± 14.14c-i	366.21 ± 17.62i-m	164.00 ± 3.78d-f	4.57 ± 0.05ef	80.33 ± 1.80c-f
IBA98051	540.59 ± 11.43a	298.79 ± 18.79bc	241.79 ± 7.37a	447.42 ± 17.91d-f	148.63 ± 0.88d-g	5.04 ± 0.23c-e	77.43 ± 0.11h
TMEB419 (Control)	357.38 ± 3.12e-k	199.63 ± 7.71h-j	157.75 ± 4.60b	341.09 ± 5.89j-m	141.46 ± 1.82e-g	4.60 ± 0.10d-f	77.88 ± 0.60h
TMS14F1195P0005	284.00 ± 5.42lm	176.84 ± 14.26j	107.17 ± 19.68c-i	308.46 ± 1.36mn	131.63 ± 12.90e-h	4.57 ± 0.05ef	79.50 ± 0.57e-g
TMS15F1467P0011	370.08 ± 9.19e-j	301.75 ± 29.94bc	68.34 ± 20.74h-l	541.92 ± 4.01bc	240.17 ± 25.93b	4.94 ± 0.47d-f	79.85 ± 0.00ef
TMS16F2006P0038	332.83 ± 4.95f-m	271.30 ± 9.02c-e	61.55 ± 13.97j-l	489.59 ± 12.49c-e	218.29 ± 3.48bc	5.40 ± 0.47bc	80.30 ± 0.64c-f
TMS16F2003P0029	339.09 ± 81.44f-m	273.71 ± 45.55c-e	65.38 ± 35.89i-l	501.75 ± 82.84cd	228.05 ± 37.30b	4.74 ± 0.19d-f	80.70 ± 1.13c-e
IITA-TMS-IBA30572	392.92 ± 25.58c-f	293.00 ± 11.07b-d	99.92 ± 14.50d-j	515.50 ± 5.19c	222.50 ± 5.90b	4.67 ± 0.09d-f	78.63 ± 0.67f-h
TMS15F1041P0003	348.92 ± 21.57e-l	293.84 ± 30.17b-d	55.09 ± 8.61kl	587.75 ± 43.13b	293.92 ± 12.96a	5.07 ± 0.37cd	80.28 ± 0.60c-f
IITA-TMS-IBA980581	220.63 ± 37.77n	207.92 ± 42.07g-j	12.71 ± 4.30m	431.13 ± 73.01e-h	223.21 ± 30.94b	5.87 ± 0.00a	91.58 ± 0.53a
TMS15F1482P0098	352.80 ± 17.50e-l	296.55 ± 13.26b-d	56.25 ± 4.24kl	576.00 ± 28.76b	279.46 ± 15.50	4.87 ± 0.09d-f	80.75 ± 1.20c-e
TMS14F1035P0005	357.83 ± 3.89e-k	319.63 ± 0.53ab	38.21 ± 4.42lm	605.34 ± 7.30a	285.71 ± 7.83a	5.80 ± 0.18ab	81.85 ± 0.57bc
TMS15F1302P0020	377.38 ± 28.81d-h	233.50 ± 11.43e-i	143.88 ± 40.24bc	403.96 ± 25.40f-j	170.46 ± 36.83de	4.54 ± 0.09f	77.08 ± 0.67h
TMS15F1466P0195	392.38 ± 0.06c-g	348.00 ± 0.95a	44.38 ± 0.88lm	632.50 ± 9.31a	284.50 ± 8.37a	5.67 ± 0.09ab	80.28 ± 0.53c-f
Mean	355.82	244.81	111.02	423.07	178.26	4.91	80.14
P level	***	***	***	***	***	***	***

Means with the same letters within the same column are not significantly different ($p < 0.05$); $^{***}p < 0.001$.
Values are means of duplicate analysis.

from TMS14F1287P0008 *gari* (95.17 RVU) may not weep easily because of its low setback viscosity compared to that prepared from TMS15F1041P0003 *gari* (293.92 RVU), which may weep easily due to its high setback viscosity. Awoyale et al. (2021a) reported a setback viscosity of between 108.59 RVU and 148.46 RVU for *gari* produced from different periods of fermentation. These values fall within the range of values for the setback viscosity of the *gari* in this study.

The *gari* produced from the TMS13F1053P0010 genotype (4.47 min) had the lowest peak time and that of the IITA-TMS-IBA980581 genotype (5.87 min) had the highest peak time. The *gari* produced from the IITA-TMS-IBA980581 genotype (91.58°C) had the highest pasting temperature, and that of the TMS15F1302P0020 genotype (77.08 °C) had the lowest (Table 3). This implies that all the *gari* samples may be reconstituted in hot water to *eba* in less than 6 min and below the boiling point of water, thus reducing energy cost (Adebowale et al., 2008). The peak time and the pasting temperature of the *gari* samples agree with the observation of Awoyale et al. (2020) for *gari* produced from different cassava varieties. In addition, some of the pasting temperatures of the *gari* samples reported in this study were below the range of values (88.75 −94.50 °C) stated for *gari* samples by Olanrewaju (2016).

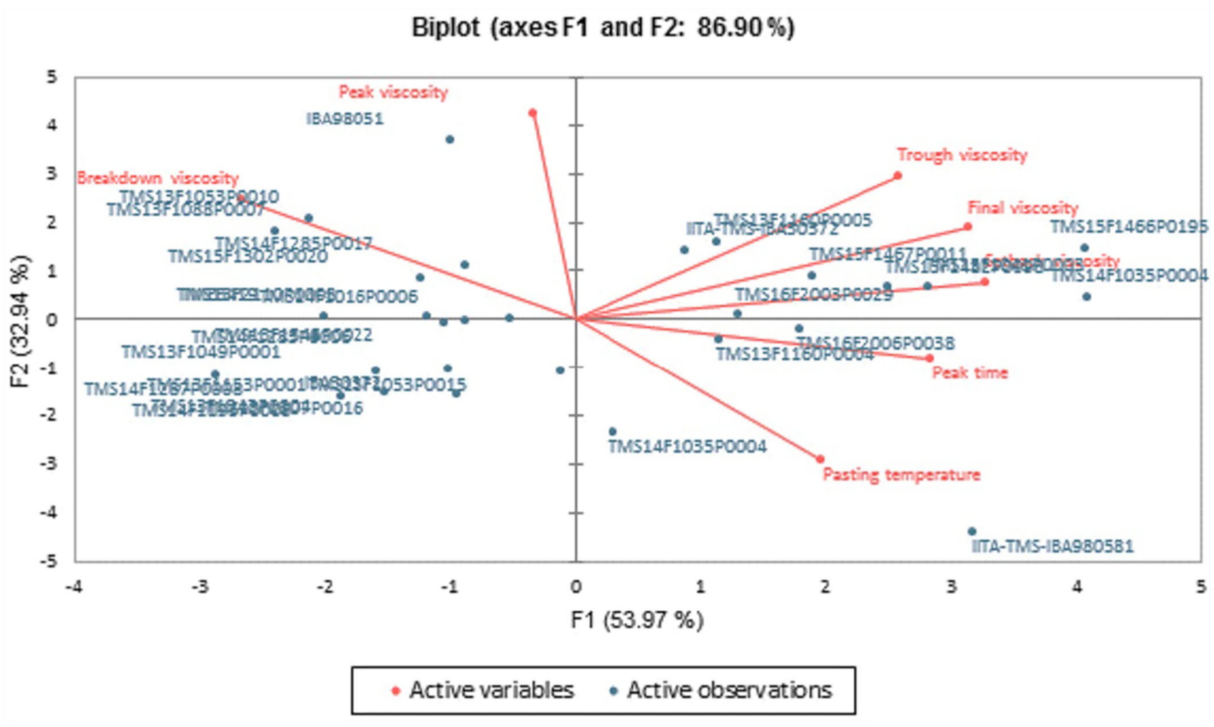

FIGURE 2
The principal component analysis biplot of the pasting properties of *gari* samples.

The PCA biplot shown in Figure 2, allowed us to distinguish the *gari* produced from different cassava genotypes based on the pasting properties. The result showed a data variance of about 86.90%, with PC1 contributing 53.97% and PC2 32.94%. The PC1 was positively correlated with the trough (r = 0.74), final (r = 0.90), and setback (r = 0.93) viscosities, and the peak time (r = 0.81) and the pasting temperature (r = 0.56) of the *gari* samples, and negatively correlated with the breakdown viscosity (r = −0.76) of the *gari* samples. The PC2 on the other hand had a positive correlation with the peak (r = 0.95) and the trough (r = 0.66) viscosities of the *gari* samples, and a negative correlation with the pasting temperature (r = −0.65) of the *gari* samples (Supplementary Table 2). The TMS13F1160P0005, TMS16F2006P0038, TMS15F1467P0011, TMS15F1466P0195, TMS15F1482P0098, IITA-TMS-IBA30572, TMS15F1041P0003, TMS16F2003P0029, and TMS14F1035P0004 genotypes were in the same quadrant with the trough, final and setback viscosities of the *gari* samples. Similarly, TMS13F1160P0004, TMS14F1035P0004, and IITA-TMS-IBA980581 genotypes were in the same quadrant with the peak time and pasting temperature of the *gari* samples. Also, the peak and breakdown viscosities of the *gari* samples were within the same quadrant with TMS13F1053P0010, IBA98051, TMS14F1016P0006, TMS14F1285P0017, TMS13F1088P0007, TMS14F1285P0006, TMS15F1302P0020, TMS13F2110P0008, and TMS13F1343P0022 genotypes and the TMEB419 variety (Figure 2). Therefore, *gari* produced from TMS13F1053P0010, IBA98051, TMS14F1016P0006, TMS14F1285P0017, TMS13F1088P0007, TMS14F1285P0006, TMS15F1302P0020, TMS13F2110P0008, and TMS13F1343P0022 genotypes may be like that of the TMEB419 variety in terms of the peak and breakdown viscosities.

Chemical composition of *gari*

Table 4 shows the chemical composition of *gari* produced from different cassava varieties. The mean of the chemical composition of the *gari* are moisture content 3.92%, ash content 0.98%, sugar content 2.57%, starch content 71.98%, amylose content 31.47% and CNP 0.47 mg HCN/kg. There were significant differences in all the chemical compositions of the gari samples (Table 4).

The moisture content of the *gari* samples ranged from 1.76% in TMS15F1041P0003 genotype to 7.44% in TMS13F1343P0004 genotype. The lower the original moisture content of a product to be stored, the better the storage stability (Sanni et al., 2006). Also, the (Codex Alimentarius Commission, 1985) stated that the stipulated moisture content of gari should be 10%. This implied that the moisture content of all the *gari* samples falls below the stipulated standard and may stay for a long time if properly packaged and stored during marketing to avoid

TABLE 4 The chemical composition of *gari* produced from the cassava genotypes and the control variety.

Cassava varieties	Moisture content (%)	Ash content (%)	Sugar content (%)	Starch content (%)	Amylose content (%)	Cyanogenic potential (mgHCN/kg)
TMS13F1049P0001	5.64 ± 1.61b	0.93 ± 0.01k-m	2.07 ± 0.01op	71.51 ± 0.05f-h	28.50 ± 0.29n	0.65 ± 0.17a-e
TMS13F1053P0010	3.94 ± 0.13d-h	0.96 ± 0.07h-l	2.25 ± 0.08mn	72.06 ± 0.06b-h	30.33 ± 0.00l	0.58 ± 0.18b-g
TMS13F1053P0015	3.82 ± 0.15d-i	1.23 ± 0.03a	3.89 ± 0.09a	71.27 ± 0.06h	30.41 ± 0.11l	0.61 ± 0.12a-f
TMS13F1088P0007	4.45 ± 0.07c-f	1.00 ± 0.04g-l	2.16 ± 0.01n-p	72.61 ± 0.54a-d	31.42 ± 0.06j	0.75 ± 0.08ab
TMS13F1153P0001	2.90 ± 0.02i-l	1.12 ± 0.01c-e	2.57 ± 0.04li	72.52 ± 0.30a-e	27.48 ± 0.11pq	0.71 ± 0.99a-c
TMS13F1160P0005	2.89 ± 0.01i-l	1.08 ± 0.04c-g	2.26 ± 0.01mn	71.92 ± 0.04c-h	34.80 ± 0.11c	0.38 ± 0.00h-k
TMS13F1160P0004	3.24 ± 0.07h-l	0.99 ± 0.04g-l	2.42 ± 0.08jk	71.85 ± 0.21d-h	34.55 ± 0.11cd	0.32 ± 0.08i-l
TMS13F1307P0016	3.86 ± 1.56d-i	1.03 ± 0.04f-j	2.87 ± 0.04ef	71.87 ± 0.79c-h	34.55 ± 0.11cd	0.57 ± 0.03c-g
TMS13F1343P0022	3.36 ± 0.13g-k	1.04 ± 0.07e-i	2.70 ± 0.03g	73.24 ± 0.69a	32.12 ± 0.23i	0.66 ± 0.01a-e
TMS13F1343P0004	7.44 ± 0.01a	1.22 ± 0.01ab	2.35 ± 0.06j-m	72.76 ± 0.04a-c	37.08 ± 0.23a	0.50 ± 0.04e-h
TMS13F2110P0008	4.80 ± 0.15b-d	1.03 ± 0.03f-j	2.82 ± 0.01e-g	71.68 ± 0.35e-h	28.29 ± 0.11n	0.40 ± 0.01h-k
TMS14F1016P0006	4.31 ± 0.08d-g	1.02 ± 0.00f-k	2.80 ± 0.07fg	72.26 ± 0.18b-g	31.91 ± 0.06i	0.52 ± 0.11e-h
TMS14F1035P0004	6.67 ± 0.07a	0.99 ± 0.05g-l	3.70 ± 0.08b	71.61 ± 0.10f-h	29.39 ± 0.06m	0.62 ± 0.00a-f
TMS14F1285P0006	4.43 ± 0.11c-f	0.97 ± 0.00h-l	2.41 ± 0.11j-l	71.51 ± 0.54f-h	31.18 ± 0.17jk	0.53 ± 0.03d-h
TMS14F1285P0017	3.53 ± 0.01f-j	1.12 ± 0.08cd	2.42 ± 0.09j-l	72.34 ± 0.04b-g	31.30 ± 0.11j	0.26 ± 0.01j-l
TMS14F1287P0008	7.06 ± 0.19a	0.80 ± 0.00o	2.47 ± 0.05ij	71.74 ± 0.64d-h	28.29 ± 0.11n	0.69 ± 0.00a-d
IBA30572	4.64 ± 0.01c-e	1.13 ± 0.08c	2.18 ± 0.01no	71.79 ± 0.78d-h	29.51 ± 0.11m	0.25 ± 0.04j-l
IBA98051	3.45 ± 0.07f-j	1.15 ± 0.06bc	2.16 ± 0.07n-p	72.55 ± 0.55a-e	35.25 ± 0.18b	0.41 ± 0.14g-j
TMEB419 (Control)	5.34 ± 0.18ab	0.84 ± 0.01no	2.03 ± 0.01p	71.51 ± 0.54f-h	33.50 ± 0.00fg	0.76 ± 0.05a
TMS14F1195P0005	4.20 ± 0.00d-h	0.92 ± 0.04n-l	2.35 ± 0.08j-m	71.92 ± 0.04c-h	27.81 ± 0.12op	0.71 ± 0.00a-c
TMS15F1467P0011	2.30 ± 0.04lm	0.99 ± 0.00g-l	3.24 ± 0.00c	71.17 ± 0.15h	32.81 ± 0.18h	0.64 ± 0.06a-e
TMS16F2006P0038	4.36 ± 0.05c-g	0.84 ± 0.01no	3.02 ± 0.08d	71.17 ± 0.20h	30.90 ± 0.12k	0.65 ± 0.03a-e
TMS16F2003P0029	3.72 ± 0.14e-i	0.85 ± 0.00m-o	2.68 ± 0.08gl	72.21 ± 0.06b-g	32.20 ± 0.12i	0.46 ± 0.06f-i
IITA-TMS-IBA30572	2.71 ± 0.02j-m	0.82 ± 0.00o	2.27 ± 0.11l-n	72.89 ± 0.07ab	33.91 ± 0.23e	0.25 ± 0.01j-l
TMS15F1041P0003	1.76 ± 0.18m	1.10 ± 0.06c-f	2.38 ± 0.04j-m	71.44 ± 0.04gh	30.12 ± 0.06l	0.30 ± 0.06i-l
IITA-TMS-IBA980581	2.45 ± 0.09k-m	0.94 ± 0.01j-m	2.07 ± 0.07op	72.34 ± 0.04b-g	27.20 ± 0.18q	0.26 ± 0.09j-l
TMS15F1482P0098	2.57 ± 0.00j-m	0.83 ± 0.01o	2.46 ± 0.06ij	71.87 ± 0.04c-h	33.33 ± 0.11g	0.19 ± 0.00l
TMS14F1035P0005	4.12 ± 0.28d-h	0.85 ± 0.01m-o	2.77 ± 0.04fg	71.69 ± 0.21e-h	34.31 ± 0.23d	0.23 ± 0.01kl
TMS15F1302P0020	1.85 ± 0.23m	0.81 ± 0.01o	2.29 ± 0.06k-n	72.40 ± 0.55a-f	27.89 ± 0.12o	0.19 ± 0.01l
TMS15F1466P0195	1.80 ± 0.21m	0.94 ± 0.03i-l	2.95 ± 0.02de	71.86 ± 0.25c-h	33.79 ± 0.40ef	0.19 ± 0.01l
Mean	3.92	0.98	2.57	71.98	31.47	0.47
p level	***	***	***	***	***	***

Means with the same letters within the same column are not significantly different ($p < 0.05$); ***$p < 0.001$.
Values are means of duplicate analysis.

moisture absorption. The moisture content of gari samples from Lagos and Environs reported by Sanni et al. (2008) (9.73–14.87%) and *gari* from different cassava varieties (except for that of TMS98/0505 variety) by Awoyale et al. (2020) (7.32–15.59%), was higher compared to that of this study. The variations in the moisture content may be due to the method cassava varieties and processing methods.

Ash content reflects the mineral status of food, although contamination during processing could indicate a high concentration (Baah et al., 2009). The ash content was higher in TMS13F1053P0015 *gari* (1.23%) and lower in that of TMS14F1287P0008 genotype (0.80%). The ash content of the *gari* samples was within the range of values (0.25–3.61%) reported for the ash content of *gari* from different cassava varieties (Awoyale et al., 2020), but lower compared to the ash content of *gari* produced using different periods of fermentation (1.61–1.68%) (Awoyale et al., 2021b). There ash content of the *gari* samples falls below the Codex Alimentarius Commission standard of 1.50%. However, the ash content of the gari samples collected from different locations in Lagos and Environs

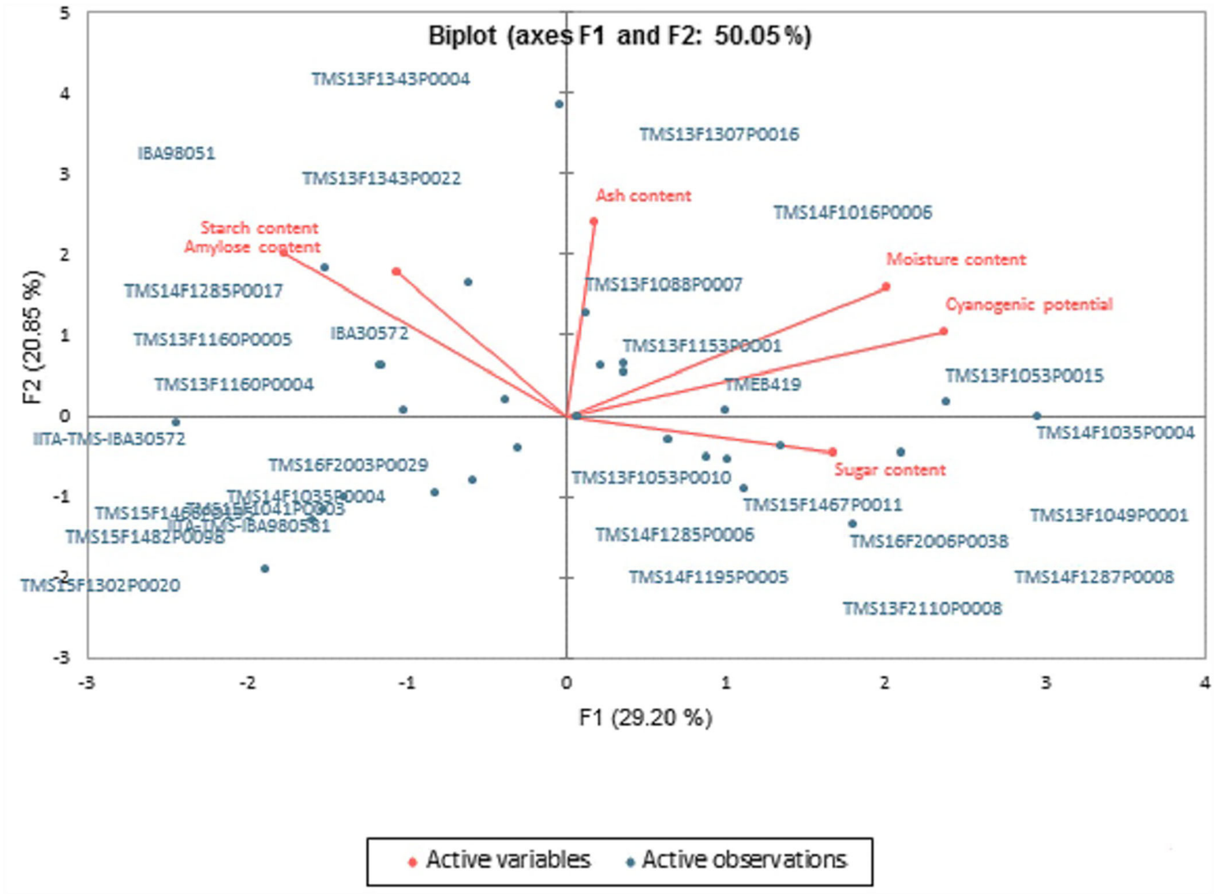

FIGURE 3
The principal component analysis biplot of the chemical composition of *gari* samples.

(1.00–1.67%) was partly higher than the ash content of the *gari* samples in this study (Sanni et al., 2008).

The starch content is one of the important quality indices that control the texture of *eba* (Oyeyinka et al., 2020). The starch content of the *gari* was lower in the TMS15F1467P0011 genotype (71.17%) and higher in that of the TMS13F1343P0022 genotype (73.24%). It is possible that the *eba* prepared from the TMS13F1343P0022 *gari* may be firmer in texture because of its high starch content, while that of the TMS15F1467P0011 *gari* may be soft-textured due to its low starch content (Oyeyinka et al., 2020). However, the starch content of the present study was lower compared to the starch content of *gari* (82.62–92.00%) produced from different cassava varieties (Awoyale et al., 2020), and the *gari* produced using different periods of fermentation (78.39–86.64%) (Awoyale et al., 2021b), but was higher compared to the starch content of *gari* samples (59.92–61.63%) from different locations reported by Abass et al. (2018). The hydrolysis of the starch into sugar during *gari* production (fermentation) may be higher in the TMS13F1053P0015 genotype (3.89%) and lower in the TMEB419 variety (2.03%) (Akingbala et al., 2005). The range of values for the sugar content of *gari* (2.78–4.29%) from different cassava varieties reported by Awoyale et al. (2020) accommodates the values reported in this study. Conversely, the sugar content of *gari* produced using different periods of fermentation (3.22–3.47%) was higher compared to that of this study (Awoyale et al., 2021b).

The higher the amylose content of the *gari*, the higher the rate of retrogradation of the *eba*. Hence, the amylose content of the *gari* determines the stability of the *eba* (Awoyale et al., 2021b). The amylose content of the *gari* ranged from 27.20–37.08%, with the TMS13F1343P0004 genotype having the highest and the IITA-TMS-IBA980581 genotype the least. The *eba* prepared from the TMS13F1343P0004 *gari* may retrograde faster because of its high amylose content compared to that of the IITA-TMS-IBA980581 *gari*, which may retrograde slowly due to its low amylose content. The amylose content of the *gari* from different periods of fermentation (29.88–30.32%) (Awoyale et al., 2021b) falls within the range of values of the amylose content of the *gari* in this study.

If cassava roots are not adequately processed before consumption, the cyanogenic potential (CNP) may be a limiting factor for humans due to its toxicity (Awoyale et al., 2020). Consequently, the Codex Alimentarius Commission (1985) set a stipulated standard of 10 mg HCN/kg for cassava products. The *gari* produced from TMS15F1482P0098, TMS15F1466P0195, and TMS15F1302P0020 genotypes (0.19 mg HCN/kg) have the lowest CNP content and that of TMEB419 variety (0.76 mg HCN/kg) had the highest (Table 4). This implied that all the *gari* samples may be safe for human consumption because the level of the CNP falls below the Codex stipulated standard of 10 mg HCN/kg. The CNP content of the *gari* produced from different periods of fermentation (1.63–4.84 mg HCN/kg) was higher compared to that of this study (Awoyale et al., 2021b). The CNP content of the gari samples reported by Sanni et al. (2008) (1.80–49.60 mg HCN/kg) and Olanrewaju (2016) (14.08–23.43 mg/kg HCN) was higher compared to that of this study. The differences in the CNP of the gari samples may be attributed to differences in the cassava varieties, length of fermentation, and roasting duration.

Figure 3 shows the PCA biplot, which allowed us to distinguish the *gari* produced from different cassava varieties based on the chemical composition. The result showed a data variance of about 50.05%, with the PC1 contributing 29.20% and PC2 20.85%. The PC1 was positively correlated with the moisture ($r = 0.65$) and the CNP ($r = 0.77$) contents of the *gari*, and negatively correlated with the starch content ($r = -0.57$) of the *gari*. The PC2 had a positive correlation with the ash content ($r = 0.66$) of the *gari* (Supplementary Table 3). The TMS13F1307P0016, TMS14F1016P0006, TMS13F1088P0007, TMS13F1153P0001, and TMS13F1053P0015 genotypes and TMEB419 variety were in the same quadrant with the ash, moisture and the CNP contents of the *gari*. Similarly, TMS14F1035P0004, TMS13F1053P0010, TMS15F1467P0011, TMS13F1049P0001, TMS14F1285P0006, TMS16F2006P0038, TMS14F1195P0005, TMS14F1287P0008, and TMS13F2110P0008 genotypes were in the same quadrant with the sugar content of the *gari*. Also, the starch and amylose contents of the *gari* were within the same quadrant with TMS13F1343P0004, IBA98051, TMS13F1343P0022, TMS14F1285P0017, TMS13F1160P0005, IBA30572, and TMS13F1160P0004 genotypes (Figure 3). Consequently, *gari* produced from TMS13F1307P0016, TMS14F1016P0006, TMS13F1088P0007, TMS13F1153P0001, and TMS13F1053P0015 genotypes may be comparable to that of the TMEB419 in terms of the ash, moisture and the CNP contents.

Textural attributes

Instrumental texture attributes of eba

The instrumental texture attributes of *eba* from different cassava genotypes are shown in Table 5. The hardness mean is 32.89 N/m^2, adhesiveness -89.27 N/m^2, mouldability 0.94, stretchability 1.03, and gumminess 30.74 N/m^2. All the instrumental texture attributes of the eba samples were significantly different (Table 5).

Awoyale et al. (2022) reported hardness as an indicator of the most direct response to taste, which has a direct relationship with chewiness, gumminess, and cohesiveness in the texture profile analysis. The hardness of the *eba* was higher in TMS15F1467P0011 *gari* (54.58 N/m^2) and lower in that of TMS14F1035P0004 *gari* (13.71 N/m^2). This means that consumers that prefer the firm-textured *eba* can consume the *eba* prepared from the TMS15F1467P0011 *gari*, while those that prefer the soft-textured *eba* can consume the *eba* prepared from the TMS14F1035P0004 *gari*. However, the range of values of the hardness of the *eba* prepared from backslopped fermented *gari* from different cassava varieties (21.03–30.22 N/m^2) was within the range reported in this study (Awoyale et al., 2022).

The degree to which the *eba* sticks to the hand, mouth surface, or teeth is known as adhesiveness (Awoyale et al., 2022). The adhesiveness of the *eba* ranged from -177.50 N/m^2 to -39.36 N/m^2, with TMS13F1343P0004 *gari* having the highest and TMS15F1482P0098 *gari* the lowest. This implies that the *eba* prepared from the TMS13F1343P0004 *gari* may be more adhesive compared to that prepared from the TMS15F1482P0098 *gari*. The high adhesiveness of the *eba* from the TMS13F1343P0004 *gari* may be attributed to the low water absorption capacity and solubility index of the *gari* (Awoyale et al., 2022). Awoyale et al. (2022) also reported the range of values of -71.20 to -42.44 N/m^2 for *eba* prepared from backslopped fermented *gari*, which was within the range of values for the adhesiveness of *eba* in the present study.

Usually, the *eba* is squeezed manually, during which the mechanical and geometrical characteristics are assessed, molded into balls with the hand, dipped into the soup, and then swallowed. Hence, mouldability is how well the product withstands a second deformation relative to its resistance under the first deformation (Awoyale et al., 2022). The *eba* from TMS13F1053P0010 *gari* (0.89) had the lowest mouldability, and the IITA-TMS-IBA980581 *gari* (0.98) was the highest. A similar range of values (0.84–0.98) was reported for the mouldability of *eba* prepared from backslopped fermented *gari* (Awoyale et al., 2022).

For consumers that chew *eba* before swallowing, the stretchability is the degree to which the *eba* returns to its original shape after compression between the teeth (Awoyale et al., 2022). The stretchability was higher in the *eba* prepared from the TMS15F1466P0195 *gari* (1.14) and lower in the *eba* prepared from TMS14F1287P0008 *gari* (0.91). The high stretchability of the *eba* from the TMS15F1466P0195 *gari* may be due to the high peak and breakdown viscosities of the *gari* (Awoyale et al., 2022). However, the values of the stretchability of the *eba* prepared from

TABLE 5 Instrumental texture attributes of *eba* produced from the cassava genotypes and the control variety.

Cassava varieties	Hardness (N/m^2)	Adhesiveness (N/m^2)	Mouldability	Stretchability	Gumminess (N/m^2)
TMS13F1343P0004	41.81 ± 0.23hi	−39.36 ± 13.60a	0.91 ± 0.00hi	0.96 ± 0.3e-g	38.01 ± 0.20ij
IBA98051	37.64 ± 0.33j	−82.31 ± 2.85c-e	0.93 ± 0.00d-h	1.01 ± 0.05a-g	34.96 ± 0.21lm
IBA30572	50.73 ± 1.78bc	−83.84 ± 3.54c-e	0.92 ± 0.00f-h	0.97 ± 0.05d-g	46.73 ± 1.54b-d
TMS13F1088P0007	32.00 ± 0.13lm	−57.82 ± 1.68ab	0.93 ± 0.02e-h	1.02 ± 0.06a-g	29.66 ± 0.75no
TMS14F1285P0006	31.21 ± 0.76mn	−42.67 ± 5.62a	0.93 ± 0.00d-h	0.99 ± 0.01c-g	29.12 ± 0.79o
TMS13F1343P0004	49.58 ± 0.48c	−103.22 ± 3.70e-g	0.91 ± 0.04hi	1.04 ± 0.05a-g	45.05 ± 2.64de
TMS13F1160P0004	44.33 ± 1.20ef	−98.29 ± 9.11e-g	0.91 ± 0.01hi	1.07 ± 0.09a-f	40.10 ± 0.59gh
TMS13F2110P0008	52.08 ± 0.40b	−109.53 ± 25.29f-h	0.91 ± 0.01hi	1.00 ± 0.00b-g	47.05 ± 0.54bc
IITA-TMS-IBA30572	51.51 ± 2.04b	−145.64 ± 12.03ij	0.94 ± 0.01c-h	1.00 ± 0.11c-g	48.07 ± 1.55b
TMS16F2003P0029	41.19 ± 0.16i	−129.69 ± 17.79hi	0.96 ± 0.02a-e	1.07 ± 0.01a-f	39.31 ± 0.54hi
TMS14F1016P0006	30.10 ± 1.24n	−68.72 ± 3.94bc	0.95 ± 0.00a-f	1.03 ± 0.04a-g	28.64 ± 1.25op
TMS13F1053P0015	38.29 ± 0.43j	−73.97 ± 4.72b-d	0.92 ± 0.02g-i	1.04 ± 0.08a-g	34.94 ± 1.08lm
TMS14F1035P0004	13.71 ± 0.36p	−85.62 ± 2.42c-e	0.95 ± 0.01b-g	1.12 ± 0.04a-c	12.98 ± 0.22q
TMS15F1302P0020	28.32 ± 0.08o	−116.75 ± 4.70gh	0.95 ± 0.00a-f	1.09 ± 0.04a-e	27.00 ± 0.08p
TMS13F1307P0016	41.92 ± 0.06g-i	−115.16 ± 0.56gh	0.93 ± 0.01e-h	1.00 ± 0.00b-g	38.60 ± 0.21hi
IITA-TMS-IBA980581	37.55 ± 0.36j	−141.87 ± 1.17ij	0.98 ± 0.00a	1.13 ± 0.07ab	36.81 ± 0.37jk
TMS13F1160P0005	35.61 ± 0.06k	−113.29 ± 4.39gh	0.95 ± 0.02b-g	1.07 ± 0.09a-f	33.59 ± 0.71m
TMS13F1153P0001	38.40 ± 0.33j	−84.07 ± 10.28c-e	0.93 ± 0.01e-h	1.00 ± 0.04b-g	35.50 ± 0.11kl
TMS13F1049P0001	33.01 ± 0.03l	−91.43 ± 13.76d-f	0.92 ± 0.00f-h	1.03 ± 0.00a-g	30.28 ± 0.08no
TMS15F1041P0003	40.86 ± 1.26i	−143.70 ± 3.11ij	0.97 ± 0.02a-c	1.09 ± 0.01a-e	39.35 ± 0.32hi
TMS14F1195P0005	43.43 ± 0.41fg	−88.31 ± 7.91c-e	0.92 ± 0.00f-h	1.07 ± 0.01a-f	39.90 ± 0.37gh
TMS14F1285P0017	45.36 ± 0.07e	−113.76 ± 2.54gh	0.91 ± 0.00hi	1.06 ± 0.03a-f	41.46 ± 0.09fg
TMS16F2006P0038	43.41 ± 0.54fg	−142.33 ± 0.56ij	0.97 ± 0.01a-c	1.09 ± 0.00a-e	42.04 ± 0.28f
TMEB419 (Control)	37.09 ± 0.01j	−118.18 ± 14.42gh	0.95 ± 0.02b-g	1.00 ± 0.00b-g	34.93 ± 0.78lm
TMS15F1466P0195	47.88 ± 0.62d	−158.88 ± 5.35j	0.96 ± 0.00a-d	1.14 ± 0.06a	45.93 ± 0.58cd
TMS14F1035P0005	42.77 ± 0.59f-g	−99.40 ± 0.04e-g	0.93 ± 0.00d-h	1.01 ± 0.06a-g	39.83 ± 0.66g-i
TMS15F1467P0011	54.58 ± 0.08a	−145.84 ± 0.47ij	0.96 ± 0.01a-e	1.10 ± 0.01a-d	52.10 ± 0.16a
TMS13F1053P0010	49.56 ± 0.37c	−100.50 ± 0.62e-g	0.89 ± 0.01i	0.94 ± 0.04fg	43.92 ± 0.06e
TMS14F1287P0008	34.63 ± 0.01k	−83.79 ± 6.15c-e	0.91 ± 0.01hi	0.91 ± 0.10g	31.27 ± 0.12n
TMS15F1482P0098	45.42 ± 0.40e	−177.50 ± 16.45k	0.97 ± 0.00ab	1.06 ± 0.08a-f	43.93 ± 0.51e
Mean	40.46	−105.18	0.93	1.04	37.7
p level	***	***	***	*	***

Means with the same letters within the same column are not significantly different ($p < 0.05$); *$p < 0.05$; ***$p < 0.001$; Values are means of six replicates.

backslopped fermented *gari* (0.88–1.06) fall within the values of the stretchability of the *eba* in this study (Awoyale et al., 2022).

Gumminess is also defined as the energy required to disintegrate a semi-solid food until it can be swallowed (Awoyale et al., 2022). The gumminess of the *eba* ranged from 12.98–52.10 N/m^2. *Eba* prepared from TMS14F1035P0004 *gari* had the lowest gumminess and the *eba* from TMS15F1467P0011 *gari* had the highest gumminess (Table 5). The gumminess of the *eba* prepared from the backslopped fermented *gari* (20.54–27.10 N/m^2) falls within the values of the gumminess of the *eba* in this study (Awoyale et al., 2022).

For the instrumental texture attributes of the *eba*, a total of about 89.51% variation was observed, with PC1 contributing 47.78% and PC2 41.73% (Figure 4). The PC1 had a negative correlation with the hardness (r = −0.72) and the gumminess (r = −0.79), and a positive correlation with the adhesiveness (r = 0.89) of the *eba*. The PC2 had a positive correlation with the mouldability (r = 0.78) and the stretchability (r = 0.76), but a negative correlation with the hardness (r = −0.69) and gumminess (r = −0.60) of the *eba* (Supplementary Table 4). The IBA98051, TMS14F1035P0004, TMS14F1287P0008, TMS13F1053P0015, TMS13F1343P0004, TMS13F1053P0010, and TMS13F1153P0001 genotypes were in the same quadrant with the adhesiveness of the *eba*. Likewise, TMS15F1467P0011, TMS14F1195P0005, TMS13F1307P0016, TMS13F1160P0004, TMS13F1343P0004, TMS13F2110P0008, IITA-TMS-IBA30572, IBA30572, and TMS14F1285P0017 genotypes were within the same quadrant with the gumminess and hardness of the *eba*.

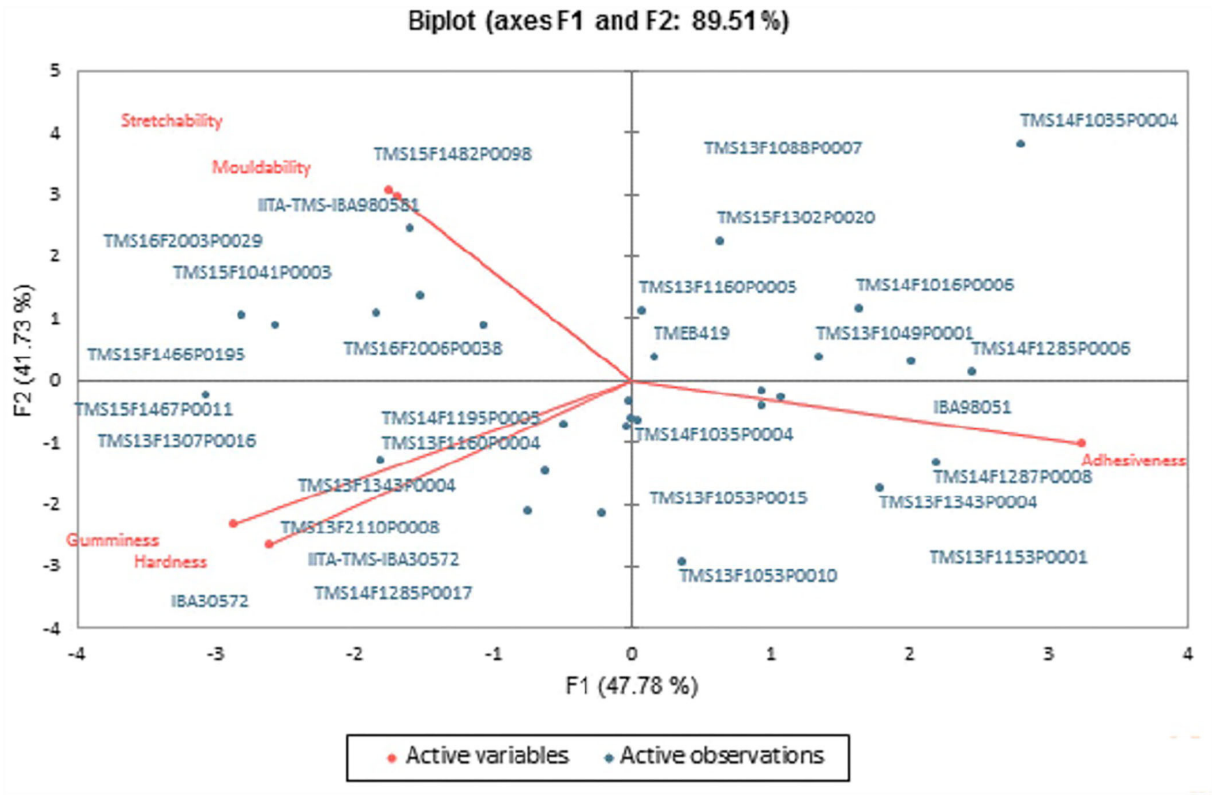

FIGURE 4
The principal component analysis biplot of the instrumental texture attributes of *eba* from different *gari* samples.

Also, the stretchability and mouldability of the *eba* were in the same quadrant with TMS15F1482P0098, IITA-TMS-IBA980581, TMS16F2003P0029, TMS15F1041P0003, TMS15F1466P0195, and TMS16F2006P0038 genotypes (Figure 4). This means that all the genotypes that belong to the same quadrant may behave similarly based on the attributes.

Sensory texture attributes of eba

The mean of the sensory texture attributes depicts that the *eba* was slightly stretchable, moderately soft, sticky, and mouldable, and were significantly different in all the eba samples ($p < 0.05$) (Table 6). A similar observation was reported by Awoyale et al. (2022) on the sensory texture attributes of *eba* from backslopped fermented *gari*. Although, the cohesiveness, mouldability, stretchability, and softness of *eba* are essential and desired at various levels depending on the region, culture, and personal preferences (Ndjouenkeu et al., 2021).

The *eba* produced from TMS14F1035P0004 *gari* was not stretchable compared to the *eba* prepared from IBA98051 *gari*, which was stretchable. This means that the *eba* prepared from IBA98051 *gari* may be preferred in some regions or cultures, due to its stretchability (Ndjouenkeu et al., 2021). The *eba* prepared from TMS14F1035P0004 *gari* was soft, but that of the IBA98051 *gari* was slightly hard. The slightly hard nature of the *eba* from the IBA98051 *gari* may be attributed to its low amylose content. This is because Awoyale et al. (2022) reported a negative and significant correlation between the hardness of *eba* and the amylose content of the *gari*. The stickiness of the *eba* prepared from TMS13F1088P0007 *gari* was moderate, while that of the TMS14F1035P0004 *gari* was stickier. Since most consumers prefer the less sticky *eba*, the *eba* from the TMS13F1088P0007 *gari* may be more acceptable compared to that of the TMS14F1035P0004 *gari*, because of its moderate stickiness (Ndjouenkeu et al., 2021). Also, the stickiness of the TMS14F1035P0004 *eba* may be due to the high amylose content. This is because a positive and significant correlation was reported to exist between the stickiness of the *eba* and the amylose content of the *gari* (Awoyale et al., 2022). The *eba* prepared from TMS14F1035P0004 *gari* was not mouldable compared to the TMS15F1482P0098 *eba*, which was mouldable (Table 6). The low amylose content of the TMS15F1482P0098 *gari* may be responsible for the mouldability of the *eba* (Awoyale et al., 2022).

The PCA biplot allowed us to distinguish the *eba* produced from the cassava varieties based on the sensory texture

TABLE 6 Sensory texture attributes of *eba* produced from the cassava genotypes and the control variety.

Cassava varieties	Stretchability	Hardness	Stickiness	Mouldabilty
TMS13F1343P0004	6.17 ± 3.29a-c	5.50 ± 3.84a-d	6.23 ± 3.67fg	7.20 ± 2.76c-f
IBA98051	6.97 ± 3.34a	6.67 ± 3.46a	6.33 ± 3.36e-g	6.63 ± 3.26d-g
IBA30572	6.33 ± 3.36ab	6.17 ± 3.29ab	6.37 ± 3.55e-g	6.23 ± 2.70e-h
TMS13F1088P0007	5.87 ± 3.34a-e	5.83 ± 4.00a-c	5.47 ± 3.66g	6.60 ± 3.06d-g
TMS14F1285P0006	5.27 ± 3.35a-e	3.90 ± 3.76d-g	7.57 ± 3.89b-f	5.10 ± 3.23g-i
TMS13F1160P0004	5.00 ± 2.58b-e	3.07 ± 2.73e-h	8.18 ± 3.27a-e	7.18 ± 2.78c-f
TMS13F2110P0008	5.54 ± 3.02a-e	3.68 ± 2.94e-g	7.43 ± 3.24b-f	8.25 ± 2.69a-d
IITA-TMS-IBA30572	4.07 ± 2.51e	4.36 ± 3.50c-f	6.25 ± 3.40fg	7.14 ± 2.52c-f
TMS16F2003P0029	5.64 ± 2.63a-e	4.68 ± 3.59b-e	6.32 ± 3.79e-g	8.93 ± 2.09ab
TMS14F1016P0006	5.28 ± 3.44a-e	2.94 ± 2.65e-h	7.44 ± 3.15b-f	6.97 ± 3.11c-f
TMS13F1053P0015	5.59 ± 3.63a-e	4.19 ± 3.37c-f	7.91 ± 3.12b-f	7.28 ± 3.14a-f
TMS14F1035P0004-	1.50 ± 1.34f	1.00 ± 0.00i	9.84 ± 0.88a	2.00 ± 1.76j
TMS15F1302P0020	4.28 ± 3.11c-e	2.28 ± 2.25g-i	9.06 ± 1.98ab	6.06 ± 2.99e-i
TMS13F1307P0016	4.97 ± 3.21b-e	3.06 ± 2.65e-h	7.97 ± 2.49b-f	6.66 ± 3.03d-g
IITA-TMS-IBA980581	4.22 ± 2.64de	3.53 ± 3.33e-h	8.31 ± 2.63a-d	7.13 ± 3.13c-f
TMS13F1160P0005	6.25 ± 3.26ab	3.06 ± 2.65e-h	7.56 ± 2.96b-f	6.00 ± 2.54e-i
TMS13F1153P0001	5.66 ± 3.15a-e	3.97 ± 2.74d-g	7.56 ± 2.96b-f	7.13 ± 3.13c-f
TMS13F1049P0001	5.53 ± 3.25a-e	2.13 ± 1.83g-i	9.06 ± 1.98ab	4.44 ± 3.27i
TMS15F1041P0003	4.72 ± 2.33b-e	3.31 ± 2.63e-h	6.63 ± 2.83d-g	8.59 ± 2.28a-c
TMS14F1195P0005	6.13 ± 3.39a-d	3.88 ± 3.02d-g	7.31 ± 3.33b-g	6.81 ± 3.07c-g
TMS14F1285P0017	5.72 ± 2.58a-e	3.75 ± 3.06d-g	7.19 ± 2.52b-g	7.81 ± 2.52a-e
TMS16F2006P0038	5.00 ± 2.41b-e	4.47 ± 3.47b-f	7.72 ± 2.95b-f	8.94 ± 2.34ab
TMEB419 (Control)	5.50 ± 3.05a-e	2.66 ± 2.34f-i	8.63 ± 2.51a-c	6.13 ± 3.39e-i
TMS15F1466P0195	4.41 ± 1.88b-e	3.94 ± 2.47d-g	7.28 ± 3.14b-g	7.25 ± 2.95b-f
TMS14F1035P0005	6.00 ± 3.23a-e	3.21 ± 2.47e-h	6.92 ± 2.78c-g	7.13 ± 2.82c-f
TMS15F1467P0011	4.83 ± 2.91b-e	4.54 ± 3.39b-e	6.54 ± 2.95d-g	8.33 ± 2.41a-d
TMS13F1053P0010	6.21 ± 3.32a-c	2.67 ± 2.01f-i	7.50 ± 2.55b-f	5.83 ± 3.38f-i
TMS14F1287P0008	5.79 ± 3.12a-e	1.83 ± 1.66hi	8.75 ± 2.21a-c	4.75 ± 3.57hi
TMS15F1482P0098	5.83 ± 3.38a-e	4.50 ± 3.11b-f	6.38 ± 3.15e-g	9.00 ± 2.40a
TMS13F1343P00022	5.21 ± 3.01a-e	2.89 ± 2.41e-h	8.29 ± 2.92a-d	6.71 ± 3.14d-g
Mean	5.29	3.72	7.49	6.78
p level	***	***	***	***

Means with the same letters within the same column are not significantly different ($p < 0.05$); ***$p < 0.001$.
Stretchability: 1 = Not stretchable, 5 = Slightly stretchable, 10 = Stretchable.
Hardness: 1 = Soft, 5 = Moderately soft, 10 = Slightly hard.
Stickiness: 1 = Not stickiness, 5 = Slightly stickiness, 10 = Stickiness.
Mouldability: 1 = Not mouldable, 5 = Slightly mouldable, 10 = Mouldable.

attributes (Figure 5). The result of the sensory texture attributes of the *eba* showed a data variance of about 84.27%, with the PC1 contributing 67.60% and PC2 16.67%. The PC1 was negatively correlated with the stretchability (r = −0.70), hardness (r = −0.90) and mouldability (r = −0.75) of the *eba* and positively correlated with the stickiness (r = 0.92). The PC2 had a positive correlation with the stretchability (r = 0.66) of the *eba* (Supplementary Table 5). Based on the sensory texture attributes of the *eba*, TMS13F1049P0001, TMS14F1285P0006, TMS13F1160P0005, TMS13F1343P00022, TMS14F1287P0008, and TMS13F1053P0010 genotypes and TMEB419 variety were in the same quadrant with the stickiness of the *eba*. Similarly, the mouldability of the *eba* was in the same quadrant with the TMS13F2110P0008, TMS15F1467P0011, TMS15F1482P0098, TMS16F2006P0038, TMS15F1041P0003, TMS16F2003P0029, TMS14F1285P0017, and IITA-TMS-IBA30572 genotypes (Figure 5). Also, TMS14F1035P0004, TMS13F1343P0004, IBA98051, TMS14F1195P0005, TMS13F1153P0001, IBA30572, TMS13F1088P0007, and TMS13F1053P0015 genotypes were within the same quadrant with the stretchability and hardness of the *eba* (Figure 5). Therefore, the *eba* prepared from the TMS13F1049P0001,

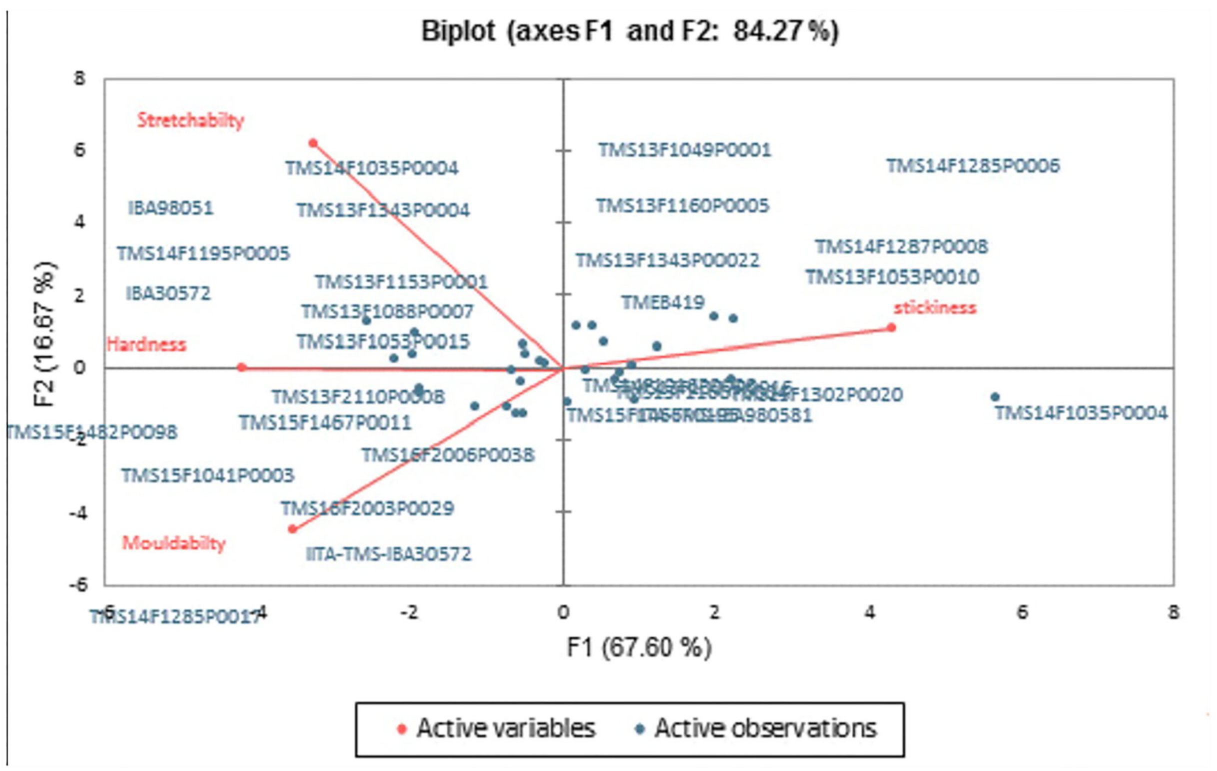

FIGURE 5
The principal component analysis biplot of the sensory texture attributes of *eba* from different *gari* samples.

TMS14F1285P0006, TMS13F1160P0005, TMS13F1343P00022, TMS14F1287P0008, and TMS13F1053P0010 *gari* may be like that of the TMBE419 variety based on the stickiness (Figure 5).

Conclusion

From the principal component analysis, *gari* made from TMS14F1285P0006 and TMS13F1053P0010 genotypes may have similar dispersibility, swelling power, and peak and breakdown viscosities as the TMBE419 variety. The stickiness of the *eba* prepared from these genotypes may also be like that of the TMBE419 variety. Therefore, TMS14F1285P0006 and TMS13F1053P0010 genotypes may be a suitable substitute for producing *gari* instead of the TMBE419 variety.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by Ethical Committee of the International Institute of Tropical Agriculture, PMB 5320 Oyo Road, Ibadan, Oyo State, Nigeria. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

WA, HO, and BM-D: conceptualization, methodology, formal analysis, investigation, visualization, writing—original draft, and writing-review and editing. BM-D, EA, and MA: supervision, project administration, and writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.984687/full#supplementary-material

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