Research Article

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Drivers of consumer acceptability of cassava gari-eba food products across cultural and environmental settings using the triadic comparison of technologies approach (tricot)

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Abstract

BACKGROUND: Nigeria and Cameroon are multi-ethnic countries with diverse preferences for food characteristics. The present study aimed to inform cassava breeders on consumer-prioritized eba quality traits. Consumer testing was carried out using the triadic comparison of technologies (tricot). Diverse consumers in villages, towns and cities evaluated the overall acceptability of eba made from different cassava genotypes. Data from both countries were combined and linked to laboratory analyses of eba and the gari used to make it.

RESULTS: There is a strong preference for eba with higher cohesiveness and eba from gari with higher brightness and especially in Cameroon, with lower redness and yellowness. Relatively higher eba hardness and springiness values are preferred in the Nigerian locations, whereas lower values are preferred in Cameroon. Trends for solubility and swelling power of the gari differ between the two countries. The study also reveals that the older improved cassava genotype TMS30572 is a benchmark genotype with superior eba characteristics across different regions in Nigeria, whereas the recently released variety Game changer performs very well in Cameroon. In both locations, the recently released genotypes Obansanjo-2 and improved variety TM14F1278P0003 have good stability and overall acceptability for eba characteristics.

CONCLUSION: The wide acceptance of a single genotype across diverse geographical and cultural conditions in Nigeria, as well as three acceptable new improved varieties in both locations, indicates that consumers' preferences are surprisingly homogeneous for eba. This would enhance breeding efforts to develop varieties with wider acceptability and expand potential target areas for released varieties.

Supporting information may be found in the online version of this article.

Keywords: consumer testing; G × E × society interactions; tricot; breeding; varietal adoption; cassava; gari-eba

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INTRODUCTION

Root and tuber crops, and cassava in particular, have global importance in food, feed and agro-industries.[1] Production, processing of raw roots, preparation and marketing of cassava-based food products are particularly important in Africa. The availability of these cassava foods satisfies a high demand and consumption among transgenerational and diverse populations. The cassava food chain has important gender-related aspects and is critical in sustaining socially and culturally diverse users across different agro-ecologies.

In Nigeria and Cameroon, cultural diversity coupled with dynamics such as an increasingly urban population[2] elicited different processing methods, varying trait preferences and varying acceptability of different varieties used by farmers and processors. Both cultural and gendered division of labor related to the value addition activities of cassava are therefore important in relation to crop improvement.[3,4] This variation in preferences is hypothesized to influence food product acceptance among consumers, which complicates breeding efforts.

Apart from meeting objectives for enhanced nutritional quality and industrial demands, cassava breeding programs have identified and prioritized two food product profiles mainly focused on food security. First, cassava for direct consumption after boiling is widely utilized in seasons/periods when yam is expensive or scarce and, second, processed foods,[5] which are critical for cassava because of the short shelf life of roots. In Africa, cassava is processed into several food products, sometimes involving fermentation of the root, which is intended both to soften it for facilitation of its malleability in secondary processed foods and to eliminate cyanogenic compounds.

The dough-like food products eba and fufu are two main important cassava-derived foods in Nigeria and Cameroon. Gari (the dry basis of eba) is a coarse granular flour essential as a marketed product as it is pre-cooked and storable. In Cameroon and Nigeria, eba is the dominant form of gari consumption. Although there are a variety of preparation techniques and names that vary from region to region, gari is fundamentally made by peeling, grating, pressing, sieving and toasting, sometimes after fermentation.[6-8] Eba (often called gari-fufu in Cameroon) is prepared by mixing gari with hot water and allowing it to simmer with stirring until smooth. The present study focuses on consumer preferences of Eba in Nigeria and Cameroon.

Consistent efforts in the last 10 years through funded projects such as Nextgen cassava (https://www.nextgencassava.org) and RTBfoods (https://rtbfoods.cirad.fr) have led to the assessment of improved cassava genotypes to meet identified demand and preferences of diverse crop users. Public breeding programs have been assessing improved genotypes on-station for genetic variability, heritability and stability of the food product yield and quality traits of interest.[9,10] Assessment of clones for food product traits at the last breeding stage using multi-disciplinary methodologies[4,11,12] provided evidence of the need for a deliberate shift in breeding priorities to user-focused, inclusive and gender-responsive approach.[11-13] Recent breeding activities have incorporated the assessment and inclusion of the post-harvest processing and consumer acceptability aspects,[4,14] informing breeders' selection accuracy and definition of genetic gains.

Assessment of improved cassava genotypes using these multidisciplinary methodologies[4,15,16] has demonstrated the relevance of different varietal preferences and varying trait prioritizations because of variation in the agro-ecological and social dimensions. Likewise, the participatory evaluation of new cassava genotypes and their derived food products[4,17] elicited the varietal effects on the quality of different types of gari-eba and fufu, as well as the effects of the cultural diversity and practices of the producing and processing populations.[6] Combining informed demand-led breeding with socially inclusive approaches, methodological innovation and triangulated transdisciplinary evidence (datasets) offer great potential for improving and redefining genetic gains, enhancing adoption and increasing social impact, which are key objectives of public breeding.[13] New standardized and scalable tools allowing the integration of different datasets can potentially improve the efficiency of conventional breeding.[5]

Linking food science measurements such as instrumental textural profile analysis (ITPA), color analysis and functional properties of the food product to the overall liking of food samples from different varieties is needed to establish which parameters represent what consumers prefer. This is crucial to facilitate the selection of genotypes for specific, dual or multipurpose food uses.[9] It is also essential to overcome the paucity of information regarding the stability of acceptability traits of cassava-eba food across cultural and environmental settings among its diverse consumers. Earlier research[4,6,15,16,18] has established that processor and consumer preferences are mainly related to the texture and color of the food products, which informed our focus on laboratory parameters related to these.

The present study used the triadic comparison of technologies (tricot) approach to consumer testing. This is a change from the conventional method used in food science for RTB breeding that tests all the varieties with each consumer working with a Likert scale. However, testing more than four to five food samples with each of the consumers and making them use a Likert scale can be time-consuming and leads to consumer fatigue, resulting in unrealistic low-quality data (Dr Bolanle Otegbayo, personal communication, Cotonou, 19 November 2021).

The novelty of tricot as citizen science is that it simplifies the task for each consumer to a concrete comparison between three samples, from which the consumer simply chooses the best and the worst sample. This avoids a rating scale approach using a Likert scale, and it avoids using many samples per consumer. To achieve this, tricot combines an incomplete block design and statistical models that work with ranking data (Plackett-Luce model).[18-20] Tricot mobilizes consumers' cognitive mechanisms of perception and judgement to avoid overburdening them by limiting the evaluation to only three samples per consumer. It aims to reflect how consumers evaluate samples in their use contexts to ensure the external validity of the test results.[18-20] According to Awoyale *et al.*,[7] the information on the suitability of varieties for cassava foods contributes to improving breeding programs. Tricot offers an analytical method related to other conventional breeding and hybrid food science approaches and datasets. The digital platform ClimMob (https://climmob.net/blog) was custom-made to manage tricot projects, from design to analysis and reporting. This decreases data management and cleaning work and enables quick feedback to citizen science partners. The platform and associate R packages have the functionality to systematically store, analyze and combine data on a year-to-year basis in line with breeders' common practice.[21] Tricot also easily allows the integration of traditional food science tools such as just-about-right and a check-all-that-apply test.[22] Soon, ClimMob will be able to export these data to breeders' databases, such as BreedBase and CassavaBase,[5] to integrate these data seamlessly into decision-making by RTB breeding programs.

In the present study, tricot was used to identify consumer acceptability of eba made from improved and commonly used commercial checks. Understanding the relationship between varieties and food products' overall acceptability is critical in meeting the food preference of gendered and socially diverse consumers.[4,20] The novel approach was used to triangulate consumer-testing datasets with food science laboratory results to validate the inclusion and prioritization of preferred laboratory-measurable quality traits to inform breeding product profiles and allow for selection towards such product profiles.

Specific objectives included: (i) examining the influence of environment, cultural settings and social dimensions of the consumers on the acceptability of cassava-eba; (ii) investigating the relation between laboratory measurements physical and functional properties and ITPA and consumer acceptability (what are they, and how do they differ concerning the environment cultural settings and the social dimensions of the consumers?); and (iii) evaluating consumer acceptability of new cassava genotypes compared to the typical farmer and processor-preferred clones.

MATERIALS AND METHODS

Within the framework of RTBfoods and Nextgen projects, a multi-partner team from ENSAI, CIRAD, IITA, CARBAP and Alliance Bioversity-CIAT implemented activities on genotypes evaluation and consumer testing in rural and urban user segments in Nigeria and Cameroon. The activity involved testing sequentially balanced randomized eba samples using the triadic comparison of technology (tricot) method.[19,20] Before the consumer testing activity in case countries, trials were established as cassava root sources. Locations were distinguished by the length of the fermenting period: three locations representing relatively longer fermentation (4–5 days) in Osun State; intermediate fermenting period (3 days) in Benue State and a short fermentation process (2 days) in the Littoral Zone in Cameroon. Cassava trials in Nigeria were grown in Ago-owu station (7.25 North latitude and 4.32 East longitude) in the derived savannah ecology in Osun State and in Ottobi stations (7.10 North latitude and 8.08 East longitude) in the southern guinea savannah ecology in Benue State. Bimodal rainfalls characterize both stations.[23] Cassava varieties were also grown in Cameroon at the Njombé IRAD station (4.55 North latitude and 9.63 East longitude), a humid forest zone with monomodal rainfall.

Trial set-up

All trials had a randomized complete block design. The trials included recently released clones (Obasanjo 2 and Game Changer) and other non-released advanced clones (TMS1, TMS2 and TMS3) (Table 1). Furthermore, three different types of check genotypes were included: (i) regionally popular varieties (TMEB1, TMEB2 and TMS6) in relation to gari and eba as informed by the Cassava Monitoring Study (CMS)[24]; (ii) local varieties (Akpu, TMEB3, Sape and Madame) selected by the champion processors in each location; and (iii) breeders' checks (TMS6 and TMSIBA). TMS6 therefore served as a popular regional check as well as a breeder's check in relation to gari and eba food products (Table 1).

Processing set-up

The processing set-up, selection of 'champion processors', sampling criteria, processing conditions and environments, and eba preparation was implemented according to Ngoh *et al.*[12] Champion processors are processors renowned in their community for their expertise in processing excellent gari products (for eba) for commercial purposes. Three champion processors were selected in communities in each State to process freshly harvested varieties into gari based on the tradition of gari processing in each location following the method described in Teeken *et al.*[4] with the exception that all varieties were harvested and processed in one batch.[12] This gari was used for the preparation of the eba samples to be tested with consumers. Based on participatory preparation of eba from gari from all the varieties with six

Table 1. Varieties used in the present study, the locations where they were grown and the ID codes used to facilitate their identification

Variety name	Description	Shortened variety name/released name (ID code)
Varieties featured in all three locations		
TMS13F1307P0016	Advanced clone	TMS1
TMS13F1343P0044	Advanced clone	TMS2
TMS14F1278P0003	Advanced clone	TMS3
TMS13F1160P0004	Released variety (2020)	Game Changer
TMS13F1343P0022	Released variety (2020)	Obasanjo-2
Regional/Local and breeders checks Benue State Nigeria		
TMS30572	Breeders' check and popular variety across Nigeria, CMS[a]	TMS6
TMEB2	Popular variety grown in Benue for gari-eba, CMS	TMEB2
Akpu	Identified as best by champion processors in Benue	Akpu
Regional/Local and breeders checks Osun State Nigeria		
TMS30572	Breeders' check and popular variety across Nigeria, CMS	TMS6
TMEB1_MS6	Popular variety grown in Osun for gari-eba, CMS	TMEB1
TMEB3	Identified as best by champion processors in Osun	TMEB3
Regional/Local and breeders checks Littoral zone Cameroon		
TMSIBA920326	Breeders' check and popular variety for boiled cassava	TMSIBA
Sape	Identified as best by champion processors in Littoral zone	Sape
Madame	Identified as best by champion processors in Littoral zone	Madame

[a] Cassava Monitoring Study.[24]

experienced preparers per locations, inclusive of the champion processors, the optimal water to gari ratio was determined for each of the varieties as to give each of the varieties the chance to express its optimal eba quality.

Format of the consumer testing experiment (using tricot-incomplete blocks)

In Nigeria and Cameroon, entry points for the sampling of participants for consumer testing (geography, recruitment, criteria) were through the community heads and tricot lead farmers (the latter working in an on-farm tricot trial project unrelated to consumer testing). Community leaders/lead farmers were asked to assist in identifying people within the community who consume eba and could describe, in clear terms, the characteristics they prefer or dislike. Efforts were made to achieve gender balance in the number of participants in rural and urban areas (villages, towns, and city areas). Food restaurants where people patronize to request eba as a meal were also identified. In Nigeria, 300 consumer tests took place in the following types of locations in each of Osun and Benue states using the Tricot method[12,20]: Villages = 120, Town = 100, City = 80. In the Littoral zone in Cameroon, there was a little more emphasis on the urban areas given the relatively high proportion of the consuming population in the city area, and 400 consumers in total were interviewed (Villages = 80, Town = 120, City = 200). In each of the three regions, eba was prepared the local way by an eba preparer from the region. All eba samples in each of the three regions were prepared by the same preparer just before a batch of consumer tests started. Samples were wrapped in plastic and kept in food flasks to keep them warm following food sellers practice in the region. An average of around 25 g of gari was used for each gari sample. Samples were prepared by breaking off a small quantity of the larger quantities prepared in traditional globe shaped cooking pots representing quantities that sellers would normally prepare at once.

Traits evaluated during consumer testing by consumers

Apart from overall liking of the samples, the following traits were evaluated for eba based on the triangulated insights obtained by earlier survey and participatory work in the three areas.[4,6,11,15,16]

Nigeria (Osun and Benue States) – Color, smoothness, moldability, stretchability, and taste.

Cameroon (Littoral zone) – Color, odor, taste, firmness and stretchability.

Traits in common are thus: color, taste and stretchability.

Considering one trait at a time, each consumer was asked to choose the best and worst of the three-eba samples. Lastly, each consumer was asked to choose their overall best and worst-liked eba sample.

Questions asked during the consumer interview included the following socio-economic information: State, Enumerator ID/Name, Sex (Options: male or female), Age (stated in years), Location type (Options: City, town and village), Ethnic group (In Cameroon, Anglophone/Francophone; In Nigeria, Yoruba, Ibo, Idoma, Igede, Tiv, and Hausa), Region of origin (Cameroon only), Phone number, Education level (No formal education, primary, secondary, and tertiary education), Occupation (options: farming, processor/trader, artisans, transporters, and civil servants) and GPS coordinates of the place of the consumer testing.

ClimMob was used to design the project and generate the sequentially balanced incomplete block design, where each consumer is offered an incomplete block of three eba samples to test (https://climmob.net/blog). Open Data Kit (ODK) was configured and installed on tablets or Android phones for trained enumerators to collect information, which is automatically stored and uploaded in ClimMob. Consumers were asked qualitative open-ended questions.[12,16]

Laboratory assessment of roots and gari/eba food products

The roots were processed in the field into gari by the champion processors following the traditional methods. Gari samples were taken to the laboratory and processed into eba using the standard operating procedures (SOP) for eba preparation in the laboratory.[25] Per locations, around 2 kg of gari, per variety from each of the three champion processors (a total of 6 kg per variety), was taken to the laboratory for the preparation of eba and analyzed for textural properties using SOP developed in the RTB Foods project.[25] Table 2 shows the parameters measured with respect to gari and eba in the laboratory.[25] For gari, the swelling power and solubility provides the extent of the interaction of associated forces within the starch granules; the higher the swelling power, the lower the associated forces within the starch granules. Colour is determined using the hunter lab color space and expressed as L^* a^* b^*. L describes the lightness or darkness of the color and has a scale between 0 and 100. a^* and b^* indicate red or green; a^* is red when the values are positive and green when negative. Also, positive b^* values show a yellow color and negative values of b^* depict a blue color.

Texture profile analysis of eba was determined using the TA. Using a XTplus Texturometer (Stable Micro Systems, Ltd (Godalming, UK) (serial number: 2-p6-z10447-01-v0038d577) coupled with a standard compression cylindrical platen of 30 mm in diameter, a double compression test was conducted on the eba with six replications for each genotype at a test speed of 1.75 mm s^{-1} and a trigger force of 5 g. Samples were presented in a uniform dimension of 2.2 cm in length and 3.6 cm in diameter at a temperature of 35°C. The probe height and force calibration were implemented on the equipment before sample analysis following the operational manual. Some of the important textural parameters measured on eba were cohesiveness and adhesiveness. Cohesiveness is the tendency of eba sample to withstand a second deformation relative to the first compression, whereas the degree at which the eba sticks to the hand depicts 'adhesiveness'. Other textural attributes and their calculations have been clearly defined in the graph provided in the Supporting information (see Supporting information, Figure S1).[25]

Table 2. Laboratory assessments on the gari and eba. (See figure S1 for elaborate explanation of ITPA parameters).

Measurements on gari: biophysical and functional properties	Measurements on eba: instrumental texture profile analysis (ITPA)
• Swelling power (%) • Solubility (%) • Color (L^*, a^*, b^*)	• Hardness (g) • Resilience (%) • Springiness (%) • Adhesiveness (g s^{-1}) • Cohesiveness • Gumminess (g) • Chewiness (g)

Statistical analysis

Consumer testing and laboratory results were analyzed in ClimMob (https://climmob.net/blog).[21] Data were analyzed using the Plackett-Luce model.[26,27] The model applies Luce's axiom that estimates the probability that an item (or a given variety) has of outperforming all the other items/varieties in a set. The Plackett-Luce is implemented in R by the package Plackett-Luce. To account for the effect of covariates, the model-based recursive partitioning[28] on variety preference was applied, comprising a decision-tree approach. To account for the effect of biophysical features of genotypes (texture profile and color spectrum) on eba preference, the alternating directions method of multipliers (ADMM) algorithm[29] was applied, which estimates the linear predictor for log-worth by genotype features. This approach helps explain the genotypes' inherent characteristics influencing consumers' preferences. best linear unbiased predictions (BLUPs) derived from the genotype biophysical features in the ADMM analysis were used.

Reported is 'worth', which is the probability of a variety outperforming the other varieties tested. Correlation between overall preference and the other traits was assessed using the Kendall tau (τ) correlation coefficient.[30] Additionally, reliability,[31] a breeding metric that measures the precision of estimated values and the potential response to selection on those estimated values compared to a check was presented.

The check varieties were Akpu, TMEB2, TMEB3, TMEB1, Madame and SAPE. Reliability, derived from the worth parameters of the Plackett-Luce model, was computed using the R package gosset.[21] All of the data and scripts used are reported via GitHub: https://github.com/AgrDataSci/rtbfoods-consumer-testing.

RESULTS

Figure 1 shows the experimental network representation of the varieties tested in Nigeria and Cameroon. The varieties in the center of Fig. 1 are the advanced clones that were evaluated, whereas the varieties around the center are varieties that were not evaluated in all three locations (Osun and Benue States, Littoral zone) but are references to the three different localities.

Relationship between the cassava genotypes assessed and the evaluated traits

The relationship between all assessed genotypes and the evaluated traits is represented using a worth map (Fig. 2). In Nigeria, the breeders' check and popular variety (TMS6) was by far the most preferred variety and the new clones Obasanjo-2 and TMS3 performed better than the regional and local checks (TMEB2 and Akpu, respectively), except for the popular local variety TMEB1, which performed equally well. Varieties TMS1 and TMS2 were clearly underperforming in both countries. It is confirmed by the breeder that TMS2 has a problem of post-harvest physiological deterioration (PPD). The variety is a sibling of Game Changer, and it clearly differs genetically for PPD trait, indicating that its inheritance is not so complex (Dr Ismail Rabbi, personal communication, Ibadan, 24 May 2022). For the clones evaluated in Cameroon, Game Changer and Obansanjo-2 performed comparably to the local check Sape and outperformed the second local check (Madame) and the breeders' check (TMSIBA) based on the overall evaluation. The overall performances of varieties TMS3 and local check (Madame) were similar and outperformed the breeders' check (TMSIBA).

Influence of environment and social covariates on the acceptability of cassava-eba among consumers

Figure 3 shows that country was the major covariant explaining variations in the data when considering country, consumption habit, ethnic group/region of origin, gender, consumption frequency of the product, education, age, state, being in agricultural work or not and urban or rural consumers. However, other social covariates were significant when only considering the Nigerian data.[32,33] Alamu *et al*. reported that consumers in cities are less diverse in their choice, and all see eba from TMS6 as the best. A specific intersectional subgroup of Igede and Tiv ethnic groups in small towns and villages (rural areas) that were involved in farming particularly liked Obasanjo-2, whereas those same ethnic groups that were not involved in farming-related activities resembled the consumers in the city with regard to taste preferences. Furthermore, people from towns and villages (more rural areas) from the Ibo, Idoma and Yoruba ethnic groups were diverse in their choice and almost equally liked BC-TMS6, leading to the conclusion that, in the rural areas, people appreciate a more considerable diversity in food product quality.

Relation between consumer-assessed gari-eba traits and laboratory measurements

Tables 3 and 4 show the relationship between the gari color, gari functional properties such as solubility and swelling power, and the Instrumental textural properties of the eba on the one hand and the overall consumer liking on the other. Table 3 shows the pooled data and Table 4 follows the nodes determined in Fig. 3. An overview of the laboratory measurements are shown in the Supporting information (Table S1).

These results show that consumers liked eba samples from gari that is less yellow and less red, in agreement with Teeken *et al*.[4] regarding processor preferences. Furthermore, there is a strong preference for eba samples with higher cohesiveness, hardness and springiness values, whereas swelling power and solubility of the gari is not related to consumer acceptability. However, when looking at these relations within the nodes, in Nigeria, there is a strong preference for eba from gari with lower swelling power and lower solubility values, whereas the inverse is true for Cameroon, where consumers prefer eba from gari with high swelling power and high solubility.

Regarding color, consumers in Nigeria prefer eba samples from gari with higher brightness, whereas other color features are not related to overall liking. In Cameroon, consumers prefer eba from gari with higher brightness and lower redness.

Regarding texture, in Cameroon, only springiness and resilience correlated with the overall liking of eba. This implies that people in Cameroon preferred eba with low resilience and low springiness values. In Nigeria, on the other hand, people liked eba with higher resilience and springiness. Furthermore, people in Nigeria preferred eba with lower gumminess (stickiness to the finger), which confirms previous findings.[4,6,15] In addition, in Nigeria, consumers liked eba, which is relatively harder and has higher chewiness values.

Consumer acceptability of new cassava genotypes compared to common farmer and processor preferred clones and breeders' checks

The acceptability of assessed cassava genotypes for eba traits are represented using a reliability breeding metric (Fig. 4). This metric is shown separately for Nigerian and Cameroon in the Supporting information (Fig. S2a,b). The precision and the potentially

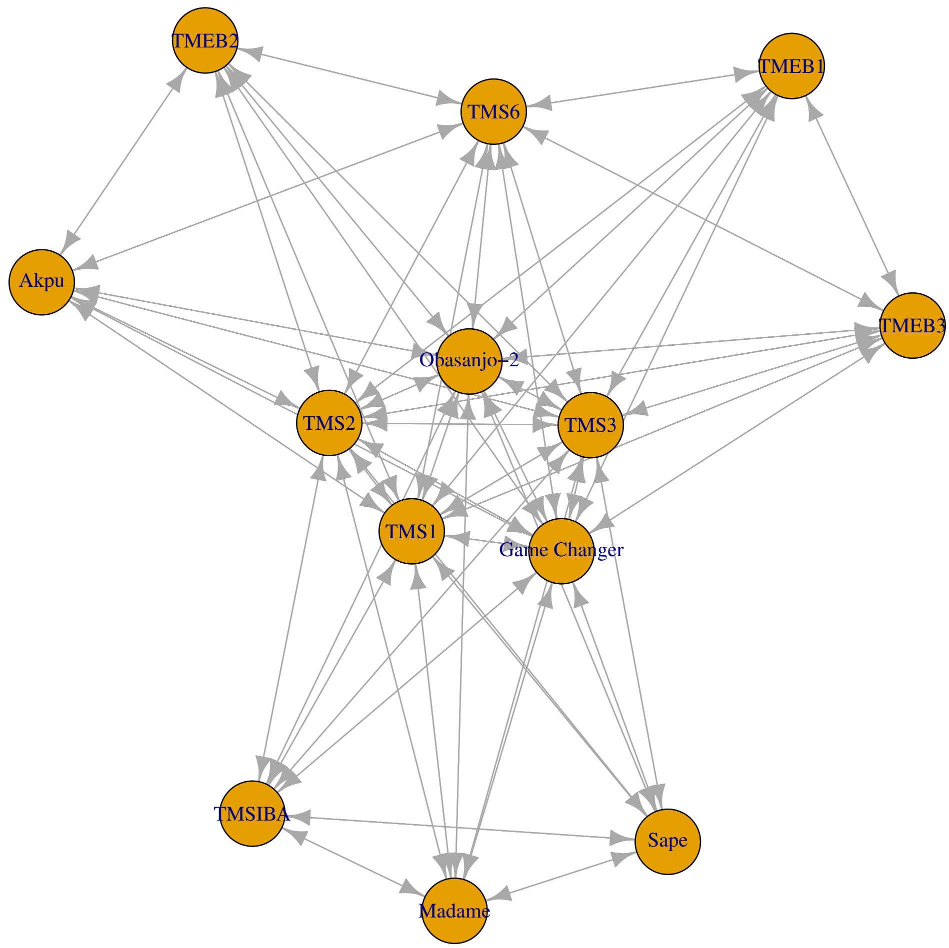

Figure 1. Experimental network representation of the varieties tested in Nigeria and Cameroon. Arrows indicate direct paths of wins and losses between each pair of varieties, indicating that the variety co-occurs in at least one experimental block. Varieties with no direct path are connected using a Bayesian prior. Five newly advanced clones have been tested in all localities (located in the center). TMB2 and Akpu are a regionally popular variety and a favorite variety as identified by the champion processors in Benue state respectively. TMEB1 and TMEB3 are a regionally popular variety and a favorite variety as identified by the champion processors in Osun state respectively. The variety TMS30572 is a breeders' check from IITA and popular variety across Nigeria and was evaluated in both the Benue and Osun locations. Sape and Madame are two local varieties identified by the champion processors in Littoral zone in Cameroon while TMSIBA920326 is a breeders' Check for Cameroon.

acceptable variety compared to a check for eba is displayed. For cassava, the reference check varieties are Akpu, TMEB2, TMEB3, TMEB1, Madame and Sape.

There was no general trend in which the local or popular variety checks were among the better performing varieties.

The breeders' check in Nigeria (TMS6) is clearly exemplary, outperforming all reference clones and new clones. The checks Akpu and TMEB2 performed consistently worse or equal to the newly bred clones. Akpu only outperformed the worst-performing clone TMS2. TMEB1 and TMEB3 (Nigeria) and Sape and Madame (Cameroon) produced the best quality eba among the regional and local checks. Given these results, three new genotypes appear to be particularly suitable with regards to eba food product quality: (i) Game Changer, which performed particularly outstanding in Cameroon (see Supporting information, Fig. S1b), (ii) TMS3 and (iii) Obasanjo 2. These last two genotypes were comparable to the best-performing checks, but offer significantly higher root and food product yield and dry matter content[34] and complete resistance to Cassava Mosaic Disease. With regard to each of the traits evaluated during the consumer testing, the relatively weaker performances of Game Changer, TMS3 and Obasanjo 2, when compared to the checks, were for color and smoothness (TMS3); smoothness, moldability, stretchability (Game Changer) and color and stretchability (Obasanjo-2). For these traits, the checks TMB2 and TMB3 (Nigeria), Madame and Sape (Cameroon) often performed better (Fig. 4).

DISCUSSION

Relationship between the cassava genotypes assessed, evaluated traits and laboratory analysis

The tricot consumer testing showed that the improved variety TMS6 (released in 1984) was overall the best in Nigeria, mainly because of its high appreciation for eba color, taste, smoothness and moldability (Figs 2 and 4). This again confirms the major importance of color and texture.[6,33] In Cameroon, Game Changer competed well with the local varieties (Fig. 3) and performed comparable to those in Nigeria, only losing out a little on mainly stretchability. This establishes TMS6 as an example reference for product quality. Given the often dual-purpose use preferred by farmers and processors,[6] it will be important to also carry out consumer testing for fufu quality with TMS6 and Game Changer to determine whether superb product quality for both products

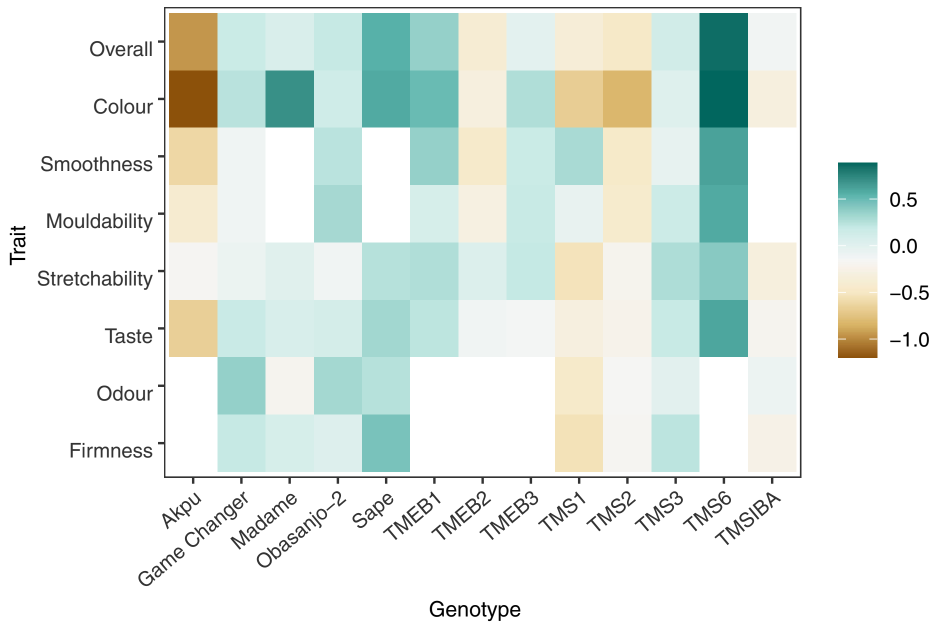

Figure 2. Relative log-worth estimates based on the overall liking for the cassava varieties evaluated in the three locations when analyzing all the data together. White fields indicate that no value was obtained because some traits are country specific and some varieties were only assessed in one of the countries.

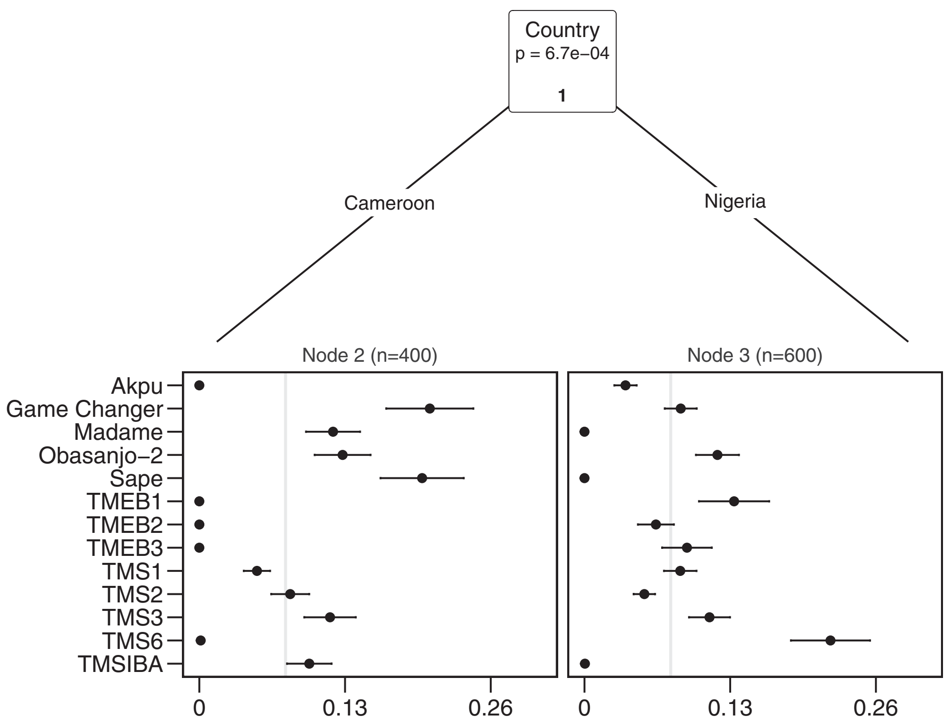

Figure 3. Plackett-Luce tree for overall appreciation of the eba samples. The horizontal axis is the probability of winning. Error bars show quasi-SEs. The grey vertical line indicates the average probability of winning (1/number of varieties). Nodes are split by the following covariate and attribute Node 2 Covariate country = Cameroon and Node 3 Covariate country = Nigeria.

(eba and fufu) can be achieved in a single variety and to see to what extent fufu and eba qualities are related.

Further improvement of color and textural properties is recommended in future breeding and releases. This is in line with the observations by Alamu *et al.*[33] stressing that color and textural attributes were related to the overall acceptability of clones.

Taste was highly correlated with the overall ranking and showed a Kendall Tau correlation of 0.62 compared to 0.51 for firmness, 0.49 for moldability, 0.47 for smoothness, 0.45 for odor, 0.43 for color and 0.33 for stretchability. However, taste is known to be less determinative in distinguishing varieties because it was not identified as a priority trait in the earlier studies cited in the methodology section.[4,6,11,15,16] Taste is a complicated trait, and

Table 3. Effect of genotypes' biophysical features of gari and eba on the consumers' preference for eba samples. Values are estimated for the whole dataset without including consumers' covariates

Feature	Estimate	SE	*z*-value	*P* (>|*z*|)
Gari color				
(Intercept)	0	NA	NA	NA
*L**	0.002	0.012	0.208	8.35×10^{-1}
*a**	−0.073	0.041	−1.768	7.71×10^{-2}*
*b**	−0.036	0.012	−2.950	3.17×10^{-3}**
Eba texture				
(Intercept)	0	NA	NA	NA
Cohesiveness	25.955	2.798	9.275	1.78×10^{-20}***
Adhesiveness	0.004	0.001	2.569	$1.02E \times 10^{-2}$*
Hardness	0.026	0.003	8.418	3.82×10^{-17}***
Gumminess	-0.147	0.018	−8.148	3.70×10^{-16}***
Chewiness	0.096	0.017	5.664	1.48×10^{-8}***
Resilience	0.514	0.229	2.244	2.48×10^{-2}*
Springiness	0.223	0.027	8.137	4.04×10^{-16}***
Solubility and swelling power				
(Intercept)	0	NA	NA	NA
Swelling power	−0.026	0.051	−0.512	6.09×10^{-1}
Solubility	−0.020	0.034	−0.588	5.57×10^{-1}

*** Significant at $P < 0.0001$.
** Significant at $P < 0.001$.
*Significant at $P < 0.05$.

there is evidence that the taste experience is also influenced by the appearance (e.g. Imran,[35] Spence[36]) of the food products, which could explain the high Kendall Tau correlation with the overall appreciation of the product. The consumer testing set-up in which the taste perception is naturally amplified as people are subject to a tasting activity can also explain the high correlation with taste. Another factor possibly explaining the high taste correlation is that the eba was presented without a sauce, whereas the eba is usually consumed with a sauce. The results, however, could be an indication that taste is more important than assumed and is probably more complex than just referring to sourness or sweetness and can have more aspect like blandness, fullness, and roundness.

The differences observed when linking overall liking to the laboratory analysis (Tables 3 and 4), can be related to the amount of fermentation (stronger in Nigeria than in Cameroon), which makes higher fermented gari become less integrated (particles less merged) and homogenous because of the lower starch content as starch content goes down because of fermentation. It can also be related to the mode of eba preparation. In Cameroon, eba is usually stirred when the cooking pot is on fire/stove, whereas, in Nigeria, especially in Osun state, the gari and hot water are not mixed on the fire/stove but in a separate bowl in which boiling water is poured onto the gari and stirred. This latter practice results in a relatively grainier eba in which the gari particles are relatively less merged. This difference in fermentation and eba preparation can make people in Nigeria prefer relatively higher cohesiveness, hardness and, as a result, a higher springiness because higher values on these parameters are more difficult to obtain given thelimited merging of the gari particles and the lower starch content (as opposed to less fermented gari prepared with more prolonged contact between gari and cooking water as practiced in Cameroon). This can also explain the preference for low values on adhesiveness in Nigeria (Table 4) because a less integrated and merged eba (with eba particles still visible) will tend to be less cohesive and thus stick to the fingers more. Stickiness to the fingers was determined as a crucial trait dislike by consumers.[6,15] At the same time, a preference exists for lower gumminess, maybe because people still prefer a relatively soft product that is easy to swallow at the same time as maintaining shape (cohesiveness). However, further research is recommended to establish the exact underlying causes of the results observed. Alamu *et al.*[33] analyzed the consumer testing data for Nigeria separately and found a similar divide in how laboratory parameters were related to the overall liking by consumers equally, pointing mainly to differences in the degree of fermentation. They related the tricot consumer testing overall liking of eba in Osun and Benue states to the color and texture, as determined by laboratory parameters, as well as solubility, swelling power and other functional properties such as the water absorption capacity of the gari. Alamu *et al.*[33] found the ethnic group as a major covariant in the data and concluded that, for ethnic groups practicing a higher degree of fermentation, cohesiveness was positively related to overall liking. The lower starch content could again explain this as well as the practice of having shorter contact with boiling water among ethnic groups that practice more fermentation. This was not the case for the other ethnic groups, nor were other ITPA elements related to the overall liking of eba for these other ethnic groups. Furthermore, solubility, as well as redness and brightness of the color, are positively related to overall liking, whereas yellowness is negatively related for ethnic groups practicing a higher degree of fermentation. For the category of ethnic groups, who practice relatively less fermentation, only the redness was positively correlated to overall liking.

Merging the datasets of Osun and Benue with the Littoral zone in Cameroon has provided more data points and more contrasting varieties (Fig. 3), especially with regards to texture. This results in texture parameters being more related to the overall liking

Table 4. Effect of genotypes' biophysical features of gari and eba on the consumers' preference for eba samples within the nodes created by the covariate 'country'

Node	Group	Feature	Estimate	SE	*z*-value	*P* (>|z|)
Gari color						
2	Cameroon	(Intercept)	0	NA	NA	NA
2	Cameroon	*L**	0.164	0.031	5.249	1.53×10^{-7}***
2	Cameroon	*a**	−0.378	0.126	−3.011	2.60×10^{-3}**
2	Cameroon	*b**	−0.010	0.049	−0.216	8.29×10^{-1}
3	Nigeria	(Intercept)	0.000	NA	NA	NA
3	Nigeria	*L**	0.059	0.017	3.416	6.37×10^{-4}***
3	Nigeria	*a**	0.007	0.064	0.116	9.08×10^{-1}
3	Nigeria	*b**	0.026	0.014	1.916	5.53×10^{-2}
Eba texture						
2	Cameroon	(Intercept)	0	NA	NA	NA
2	Cameroon	Cohesiveness	22.230	264.531	0.084	9.33×10^{-1}
2	Cameroon	Adhesiveness	0.063	0.336	0.188	8.51×10^{-1}
2	Cameroon	Hardness	0.162	0.162	1.004	3.15×10^{-1}
2	Cameroon	Gumminess	−0.576	0.984	−0.585	5.58×10^{-1}
2	Cameroon	Chewiness	3.245	2.563	1.266	2.05×10^{-1}
2	Cameroon	Resilience	−35.435	11.125	−3.185	1.45×10^{-3}**
2	Cameroon	Springiness	−3.565	0.674	−5.285	1.26×10^{-7}***
3	Nigeria	(Intercept)	0.000	NA	NA	NA
3	Nigeria	Cohesiveness	89.771	10.641	8.437	3.27×10^{-17}***
3	Nigeria	Adhesiveness	−0.067	0.005	−12.276	1.22×10^{-34}***
3	Nigeria	Hardness	0.397	0.062	6.435	1.23×10^{-10}***
3	Nigeria	Gumminess	−2.642	0.401	−6.594	4.27×10^{-11}***
3	Nigeria	Chewiness	2.452	0.377	6.496	8.24×10^{-11}***
3	Nigeria	Resilience	1.910	0.604	3.164	1.56×10^{-3}**
3	Nigeria	Springiness	3.713	0.566	6.558	5.45×10^{-11}***
Solubility and swelling power						
2	Cameroon	(Intercept)	0.000	NA	NA	NA
2	Cameroon	Swelling Power	7.630	0.882	8.655	4.92×10^{-18}***
2	Cameroon	Solubility	10.034	1.159	8.655	4.94×10^{-18}***
3	Nigeria	(Intercept)	0.000	NA	NA	NA
3	Nigeria	Swelling Power	−9.715	0.912	10.655	1.65×10^{-26}***
3	Nigeria	Solubility	−1.263	0.261	−4.844	1.27×10^{-6}***

*** Significant at $P < 0.0001$.
** Significant at $P < 0.001$.

among those who practice a higher degree of fermentation. The Cameroon case provided data points related to an even smaller degree of fermentation than practiced in Benue and Osun. In Cameroon, representing the least fermentation, it is clear that consumers do not like eba, which is gummy or has a high springiness value (Table 4). The higher starch content because of less fermentation and prolonged contact with hot water during eba making induce a more homogenous merging of starch, more easily resulting in a hard tough gummy texture. This is less likely in Osun and Benue, in Nigeria, where there is less prolonged hot water contact during eba making.

Consumer acceptability of new cassava genotypes compared to common farmer and processor preferred clones and breeders' checks

The results shown in Fig. 4 indicate that there is a clear difference in the performance of the new clones in relation to the checks (the regional and local checks). Game changer performed comparable to some checks in Nigeria but particularly well in Cameroon, whereas Obasanjo 2 and TMS3 performed well in both Nigeria and Cameroon. Although Game Changer was developed with a specific focus and evaluation with mainly farmer processors in Nigeria, this result shows the potential of improved varieties to perform even better in a region for which they were not originally bred (Fig. 3). The similarity in performance across the countries of these clones (Obasanjo 2 and TMS3) also highlights the similarity in suitability in two different regions distinguished by different agro-ecologies and the degree of fermentation utilized in processing. These similarities in performance indicate that consumer preferences may be consistent even when many factors differ: where the trials were grown, the way of processing, and consumers with different cultural and culinary backgrounds.

The results indicate that the degree of fermentation explains a large part of the variance observed. This is encouraging for breeders, as this means food scientists will only have to develop two separate laboratory SOPs for gari processing (one with more and one with less fermentation) and eba preparation to capture the main variability in evaluating clones. The particular good

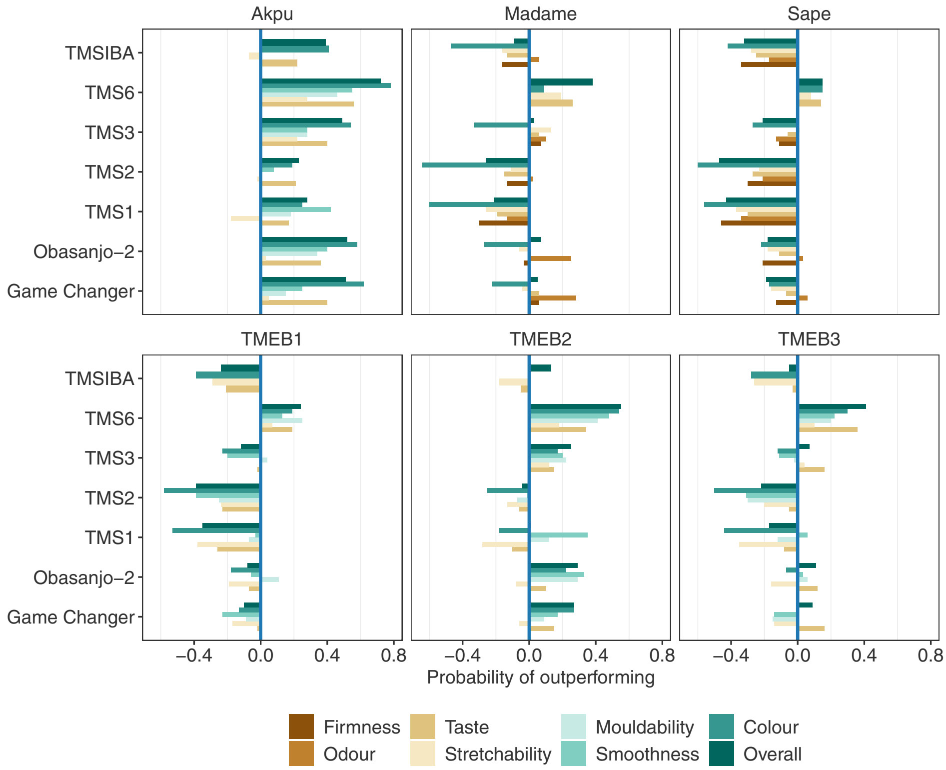

Figure 4. Reliability of cassava varieties (advanced clones – vertically listed – *versus* checks - horizontally listed) assessed for studied eba traits and overall acceptability in the three locations when analyzing all the data together. Each panel represents the performance of advanced clones against a local or regional check. Probabilities superior to 0 (blue vertical line) represent an advantage of the advanced clone against the respective check for each of the traits accessed.

performance of Game changer in Cameroon and the superb performance of TMS-6 in Nigeria show that participatory evaluation of clones is highly informative, especially in identifying contrast with reference clones currently used by farmers and processors (Fig. 4). A significant difference is crucial to incentivize farmers and other value chain actors to adopt a new variety to replace or complement what they rely on.[37] Exploiting these large differences is probably the best way for breeders to incentivize adoption and create impact from new clones.

In conclusion, the present study has shown that participatory feedback loops in the breeding process, combined with verification and testing of released and advanced clones in different environments, have proven effective with respect to addressing social impact among the value chain actors involved, which is particularly crucial for public breeding aimed outcomes.[10] Juxtaposing agronomic performance, along with food products processing evaluation by farmer-processors and consumers, offers a powerful tool for ensuring that new clones are relatively suitable to all value chain actors. Systematized data collection, using tricot on field-testing,[4,18] centralizes on-farm testing data and makes them compatible with and complementary with breeders' trial data. Additionally, tricot consumer testing procedures and processing diagnostics allow screening with respect to the relative drudgery involved in the processing of varieties.[34,38] This also facilitates moving to triangulation of traits and into a direction of complementarity where the focus is on which varieties and traits are most needed in addition to what farmers, processors and consumers currently use in different agro-ecological and cultural settings and as response strategies to conflict and climatic changes.[39]

AUTHOR CONTRIBUTIONS

OO, BT, AB, KS, RN, MA, EA, AA, JE, FN, DD and ABo were responsible for study conceptualization. OO, AB, KS, BT, RN, MA, EA, AA, JE and FN were responsible for data curation. KS, OO, BT, AB, AA, MA, EA and JE were resposible for formal analysis. OO, AB, RN, MA, FN and BT were responsible for investigations. OO, BT, AB, KS, MA, EA, AA and JE were responsible for methodology. BT, KS, EA, JE, ABo and DD were responsible for supervision. OO, BT, AB, RN, MA and EA were responsible for writing the original draft. OO, BT, AB, KS, RN, MA, EA, AA, DD and ABo were responsible for reviewing and editing. OO, BT, AB, MA, EA, DD and ABo were responsible for project administration.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in GitHub at https://github.com/AgrDataSci/rtbfoods-consumer-testing.

ETHICAL STATEMENT

The research described in this manuscript (from laboratory through consumer preferences interviews and surveys) was approved by the International Institute of Tropical Agriculture (IITA) internal ethical review board (IRB) and implemented according to the IITA IRB policy (https://www.iita.org/wp-content/uploads/2019/06/IITA-IRB-Policy-June2016.pdfe). The IITA is mandated to conduct research in the country where this consumer testing occurred (Nigeria and Cameroun). Written informed consent was obtained for all study participants.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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