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Research Article

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Analysis of association of sensory and laboratory assessments for quality and consumer acceptability of steamed East Africa highland bananas

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Abstract

BACKGROUND: The relevance of several characteristics for the acceptability of steamed East Africa bananas (matooke) was assessed using consumer-preferred characteristics, the overall liking scores, check-all-that-apply (CATA) and the Just About Right scale. The study was conducted in rural and urban locations in three banana growing regions of Uganda. Two landraces and two hybrids were processed into matooke. Twelve trained panellists evaluated color, taste and texture sensory characteristics.

RESULTS: Consumers scored matooke from landraces as the most liked. The CATA test showed that the most important characteristics were: smooth mouthfeel, soft to the touch, not sticky, moldable, deep yellow color, attractive, good matooke taste and smell. Principal component analysis confirmed that most of the preferred sensory characteristics were associated with the local genotypes, whereas the less preferred characteristics were associated with hybrids. Correlation analysis revealed strong positive correlations between the consumer assessed characteristics, hardness by touch, softness to touch and yellowness, as well as quantitative laboratory characteristics (moldable, hardness by touch, softness and yellowness) of the steamed matooke. Color assessed by consumers was strongly correlated with the laboratory-assessed color indicators.

CONCLUSION: The strong associations observed between laboratory-assessed and consumer-based characteristics (moldable by touch and yellowness) suggest the possibility of predicting consumer characteristics using quantitative laboratory sensory assessments. Matooke taste as assessed by consumer panel is strongly associated with smooth texture and deep yellow color, which were the characteristics associated with landraces in the laboratory sensory assessment.
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Keywords: matooke; breeding; attributes; sensory; consumer acceptance

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INTRODUCTION

Consumer participation in the development of new products is vital for identifying the needs of the users.[1,2] These needs must then be incorporated into the final products before they are released to the users.[3–5] Consumers' perception of characteristics is influenced by the product's intrinsic and extrinsic indicators.[6] Similarly, preferences arise from a combination of product and consumer characteristics.[7] Several studies[8–11] have reported that consumer acceptance is important for the new food product development process. Product development processes that ignore the prospective users' interests often results in rejection of the products.[1] Understanding the consumer's perception of different sensory characteristics and the contribution of each characteristic to the acceptability is therefore very useful information for identifying potential areas requiring improvement in the product development process.[12] Consumers' decisions to purchase a product is influenced by sensorially-assessed traits, first the appearance and then culinary characteristics, including taste and texture.[2,13] A clear and accurate understanding of these sensory characteristics is key in the development of end user acceptable products.[14]

Cooking banana is source of food and income to over 30 million people in East Africa.[15,16] Grown by over 70% of farmers in Uganda, the cooking bananas are composed of over 100 indigenous varieties.[17] All these varieties are susceptible to banana pests and diseases which have necessitated their improvement through breeding.[15,18–21] However, most of the hybrids in bananas and other horticultural crops are often rejected by end users because of their poor culinary qualities.[22–27] This is because often breeders focus on generating hybrids that are resistant to pests and diseases, as well as high yield traits, but not the consumption attributes.[23]

Currently, banana breeders generate a large number of hybrids to increase the chances of finding an acceptable variety. The hybrids are then evaluated through four stages including early, primary, on-farm and farmer led multi-location trials, which is an expensive process. This is done because the breeders lack information on the characteristics that consumers prefer in the hybrids that would allow selection of acceptable hybrids as early as possible in the evaluation process.

User involvement in the development of new hybrids for production of steamed East Africa bananas (matooke) by breeding programs tends to focus on characteristics preferred by farmers and traders[22,23,28] and less on the needs of consumers. The aim of the present study was to evaluate whether the qualitative indicators of the consumer preferred characteristics of steamed matooke can be associated to quantitively laboratory-assessed indicators of those characteristics to aid matooke hybrid development programs.

MATERIALS AND METHODS

Sample selection and preparation

Four banana genotypes were used for this study. Nakitembe and Kibuzi, the highly preferred landraces were, used as local checks,[29] whereas NARITA 4 and NARITA17 represented advanced matooke hybrids under on-farm evaluation.[30] A pre-screening exercise by NARO identified NARITA 4 and NARITA17 as the most promising genotypes that produce moderately acceptable food based on previous sensory evaluations with farmers.[29] These were suitable candidates for consumers to evaluate in the field and characterized in the laboratory using instrumental and biochemical techniques, as well as a descriptive sensory panel.

Green mature cooking bananas were harvested, peeled, wrapped in banana leaves, steamed under same cooking conditions and mashed. All the four varieties were steamed in one big saucepan as separate bundles marked with distinct colour strings to ease identification.[23,29,31] At each sensory panel session, four cooked banana samples were coded with three-figure random numbers and served. At least 30 g per genotype was served and evaluated one at a time to each participant, in a random order to a panel of 300 consumers, 172 of whom were females aged > 18–60 years.[31,32] Clean water was provided for washing the mouth after each taste and a period of 15 min was allowed between one tasting and another. The wiling consumers were recruited from Mbarara (99 consumers), Hoima (100 consumers) and Wakiso (101 consumers) districts in southwestern, western and central Uganda, respectively, mobilized and invited through the local leadership from among matooke consumer communities.

The panel first evaluated the visual appearance and tactile characteristics on a nine-point hedonic scale[32,33] using a list of characteristics previously generated with matooke users.[34] Samples were then tasted one at a time to assess overall liking, flavor, sweetness, texture, mouthfeel and aftertaste. The consumer panel assessed the characteristics color, softness by touch and mouthfeel using a Just-About-Right (JAR) scale,[31] whereas a check-all-that-apply (CATA) test was used to confirm the importance of the characteristics in the overall liking of the product.

Quantitative descriptive analysis (QDA)

QDA was conducted at the food Biosciences laboratories of the National Agricultural Research Laboratories (NARL) by a trained panel of 12 members (eight males and four females) as described by Nowakunda *et al.*[35] This panel consisted of researchers and technicians who are staff of NARL. They were recruited and trained according to guidelines in the RTB foods sensory analysis manual.[36] The panel generated a vocabulary that was used during the analysis. Each of the attributes had a reference and these were; yellow color – ripe banana peel; homogeneity of the color – uniform ripe banana peel with no other shades of color; firmness – boiled egg yolk; smoothness – no lumps after mashing; sweetness – diluted sucrose; astringency – concentrated tea; sourness – unripe mango; matooke aroma – steamed matooke; pumpkin aroma – steamed pumpkin; and grassy aroma – freshly cut grass. An intensity scale (0–10) was used to rate the attributes, where 10 was the highest intensity.[33,37] The performance of the panel was assessed by the ability of the participants to discriminate the samples, how they were repeatable and how they were in agreement with the rest of the members.[36,37]

The banana samples used in the field (Nakitembe, Kibuzi, NARITA 4 and NARITA17) were the same as those analyzed in the laboratory for quantitative indicators by descriptive sensory analysis and instrumental analyses. The samples from the four genotypes were prepared and served according to a protocol developed and described at the Food Biosciences Laboratory of NARL.[35] Panelists were each seated in well-lit individual booths that had sinks where they rinsed their mouths between tasting the samples. A reference sample for each of the cooked bananas was placed on a disposable plate and a thermometer was inserted to read the core temperature. This was to ensure that the tasting temperature of the samples by all the panelists is uniform. The panelists were served one sample (temperature above 85 °C) at a time and presented with a glass of water for rinsing their mouths. Panelists

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Table 1. Socio-economic profiles of consumers interviewed in all the districts

Variables	Total sample All (n = 300)	Location		
		Mbarara (n = 99)	Hoima (n = 100)	Wakiso (n = 101)
Average age (years)	36.6	37.4	33.8	38.6
Education level (years in school)	7.6	7.0	6.9	8.8
Gender (%)				
Male	42.7	43.4	54.0	30.7
Female	57.3	56.6	46.0	69.3
Marital status (%)				
Single	19.7	16.2	16.0	26.7
Married	72.0	73.7	80.0	62.4
Divorced/separated	4.7	6.1	3.0	5.0
Widow	3.7	4.0	1.0	6.0
Occupation of the consumer				
Farmer	54.2	62.2	67.4	31.5
Full time salary employed	6.9	5.1	7.1	8.7
Part time wage employed	6.6	4.1	7.1	8.7
Self-employed	30.2	17.6	16.3	47.8
Other	2.1	1.0	2.0	3.3
Consumption frequency of matooke (%)				
Every day	30.0	51.5	9.0	29.7
Once a week	10.7	6.1	21.0	5.0
Several times a week	48.7	35.4	52.0	58.4
Once a month	3.3	2.0	8.0	0.0
Several times a month	7.3	5.1	10.0	6.9
Forms in which matooke is consumed (%)				
Steamed mashed	43.0	39.0	46.0	44.6
Boiled mashed	15.0	18.0	12.0	14.9
Katogo	35.0	35.0	35.0	33.2
Roasted	4.0	4.0	5.0	5.1
Empogola	3.0	5.0	2.0	2.3

Table 2. Overall liking of the steamed matooke in all the districts

Genotypes	Mean overall liking scores (n = 300 consumers)
Nakitembe	7.45 a
Kibuzi	7.09 a
NARITA17	5.68 b
NARITA 4	4.99 c

Overall liking was rated on a nine-point scale from 1 = dislike extremely to 9 = like extremely.
Different lowercase letters correspond to products that are significantly different.
Tukey's test ($P < 0.05$).

were only signaled to start tasting the samples when the temperature of the reference sample read 75 °C.

The sensory parameters assessed were: appearance, texture in the mouth, texture by touch, taste, impression and aroma.[35] Samples were evaluated and scored against the developed descriptors.[35,37] The appearance of matooke was described by color and homogeneity of the color, whereas texture was described by firmness, moistness and smoothness, all by mouth, and hardness, moldability and stickness were measured by touch.[35,37]

The laboratory instrumental parameters were: hardness, adhesiveness and cohesiveness assessed with a texture analyzer (TMS-PILOT texturometer; Mecmesin, Slinfold, UK). Color coordinates (L^*, a^*, and b^*) were assessed with a chromameter (CR-400; Konica Minolta, Tokyo, Japan) with an 8-mm measuring head L^*(Raw), b^*(Raw), L^*(Cooked) and b^*(Cooked).[35]

Data analysis

Data were analyzed using SPSS, version 23 (IBM Corp., Armonk, NY, USA) and XLSTAT 2019 (Addinsoft, Paris, France) to examine links between the sensory descriptors and laboratory quantitively measured indicators.[36,38]

Overall liking

Analysis of variance (ANOVA) was performed to identify any significant differences in overall liking scores between the four matooke banana varieties (n = 300 consumers) and quantitative sensory laboratory data (n = 12 panellists). Multiple pairwise comparisons were applied using Tukey's test. $P < 0.05$ was considered statistically significant.

JAR

In the JAR scaling, the consumer ratings for all the liking of steamed matooke characteristics were conducted as described by Yang and Lee.[13] The JAR results were analyzed through a penalty analysis using XLSTAT 2019, for identifying the potential

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directions for consumer demand of each steamed matooke product characteristic based on acceptability.

CATA tests

Frequency of the citation of CATA sensory characteristics for each product sample was summarized using a contingency table. This contains the number of assessors that checked a particular characteristic to describe a product.[39] ANOVA, using a generalized linear model, was conducted to evaluate the samples and the effects of their interactions. Duncan's multiple range test was used for post-hoc comparisons between steamed matooke samples. $P < 0.05$ was considered statistically significant.

Principal component analysis (PCA) linking qualitative and quantitative data

PCA was used to determine the mean values of different characteristics and describe their relationships with the matooke samples.[40] PCA was used to summarize the relationships between CATA sensory characteristics, product samples and mean overall liking of each product scored by all the consumers, as well as for linking qualitative and quantitative data.

RESULTS

Consumers' characteristics and their matooke consumption habits

Over half of the consumer panellists in all districts were female with exception of Hoima (Table 1). Over 70% were married with families. More than 60% of consumers in Mbarara and Hoima practiced farming, whereas, in Wakiso, it was only 30%. All of the people interviewed were matooke consumers, with over 30% eating matooke every day. The most common form of preparing matooke was steaming followed by boiled fingers locally known as *katogo*.

The consumers scored steamed matooke products from Nakitembe and Kibuzi as the most liked whereas those from hybrids NARITA17 and NARITA 4 were the least preferred, particularly the latter (Table 2). The descriptions for the liking data and the JAR variables are shown in Fig. 1. Color (Fig. 1A) was scored in a JAR category ranging from too light to too dark. Over 70% of the consumers considered that all the steamed matooke products from all genotypes possessed the preferred color, with exception of NARITA 4 (17% considered the product to be too dark).

The softness in hand of the steamed matooke product from NARITA 17 showed higher percentages of the JAR responses compared with NARITA 4 (Fig. 1B). Consumers considered hybrid NARITA 17 to be soft as they liked, whereas NARITA 4 was

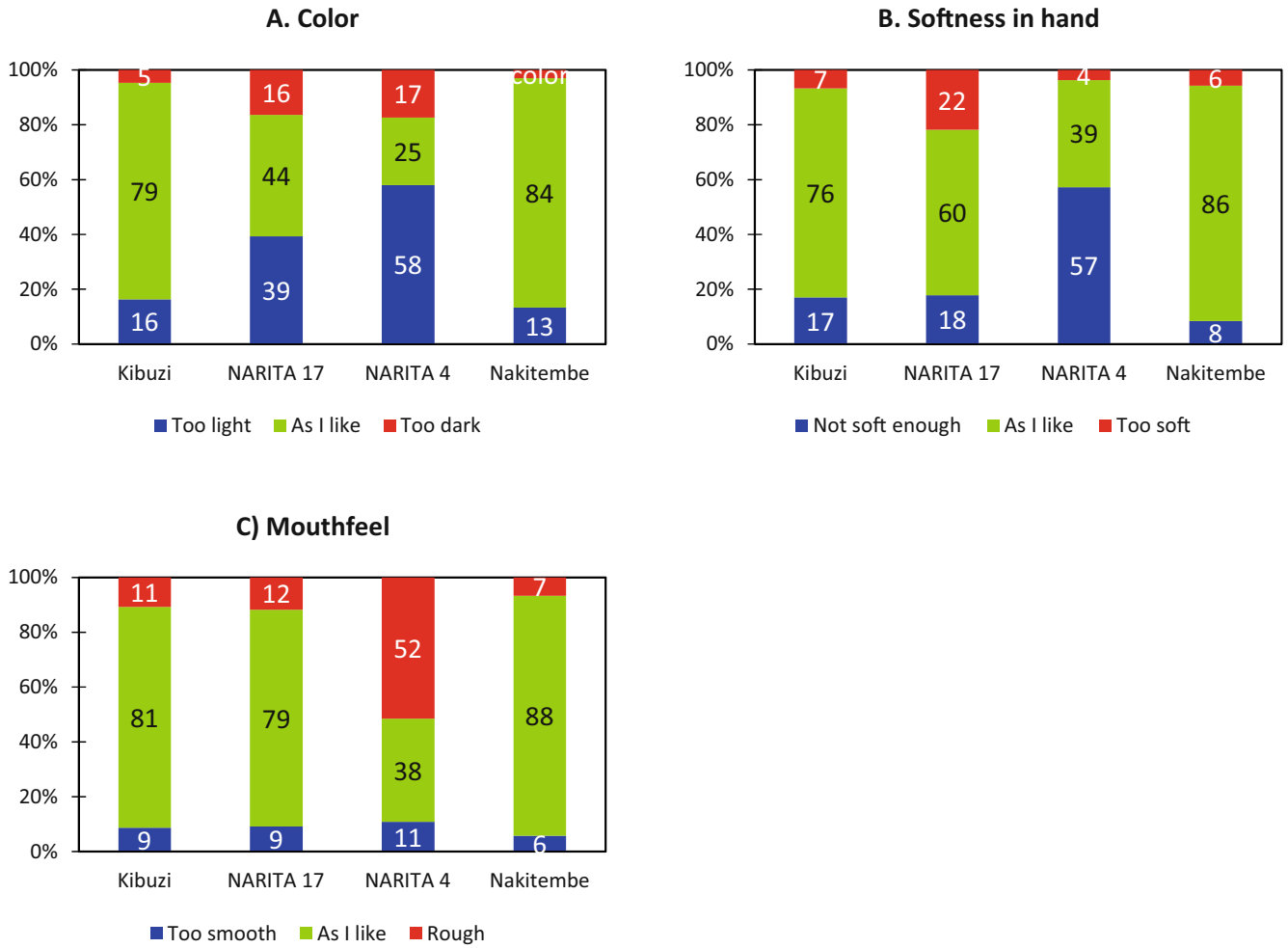

Figure 1. Percentage of consumers rating (A) color, (B) softness in hand and (C) mouthfeel using the JAR scale.

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Table 3. Penalty analysis for the JAR attributes of the four matooke genotypes

Varieties	Attribute	Level	%	Mean (overall liking)	Mean drops	*P*-value	Penalties
Kibuzi	Colour	Too light	16.3	5.7	1.7		
		As I like	79.0	7.4			1.9
		Too dark	4.7	4.8	2.6		
	Softness in hand	Not soft enough	17.0	5.4	2.1		
		As I like	76.3	7.5			2.0
		Too soft	6.7	5.6	1.8		
	Mouthfeel	Too smooth	8.7	4.5	3.0		
		As I like	80.3	7.4			2.1
		Rough	10.7	6.0	1.4		
	Taste	Not sweet enough	26.3	5.3	2.3	< 0.0001	
		As I like	73.0	7.6			2.2
		Too sweet	0.7	8.5	-0.9		
		Not enough aroma	24.7	5.4	2.2	< 0.0001	
	Smell/aroma	As I like	74.7	7.5			2.1
		Too much aroma	0.3	8.0	-0.4		
NARITA 17	Colour	Too light	39.3	4.8	2.1	< 0.0001	
		As I like	44.3	6.9			2.2
		Too dark	16.3	4.4	2.4		
	Softness in hand	Not soft enough	17.7	4.4	2.0		
		As I like	60.0	6.4			1.9
		Too soft	21.7	4.6	1.8	< 0.0001	
	Mouthfeel	Too smooth	9.0	4.1	2.0		
		As I like	78.3	6.1			2.0
		Rough	11.7	4.1	2.0		
	Taste	Not sweet enough	47.0	4.4	2.5	< 0.0001	
		As I like	49.3	6.9			2.5
		Too sweet	3.0	5.0	1.9		
	Smell/aroma	Not enough aroma	46.3	4.6	2.0	< 0.0001	
		As I like	52.3	6.7			2.1
		Too much aroma	0.7	3.5	3.1		
NARITA 4	Colour	Too light	58.0	4.7	1.9	< 0.0001	
		As I like	24.7	6.5			2.0
		Too dark	17.3	3.9	2.6		
	Softness in hand	Not soft enough	56.7	4.4	1.6	< 0.0001	
		As I like	38.7	6.0			1.7
		Too soft	3.7	4.1	1.9		
	Mouthfeel	Too smooth	10.7	3.8	2.5		
		As I like	37.0	6.2			1.9
		Rough	50.7	4.4	1.8	< 0.0001	
	Taste	Not sweet enough	59.0	4.2	2.1	< 0.0001	
		As I like	37.7	6.3			2.1

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Table 3. Continued

Varieties	Attribute	Level	%	Mean (overall liking)	Mean drops	*P*-value	Penalties
		Too sweet	1.0	6.3	-0.0		
	Smell/aroma	Not enough aroma	56.0	4.2	1.8	< 0.0001	
		As I like	40.0	6.1			1.8
		Too much aroma	1.3	5.0	1.1		
NAKITEMBE	Colour	Too light	13.3	6.1	1.7		
		As I like	83.7	7.8			2.0
		Too dark	3.0	4.4	3.3		
	Softness in hand	Not soft enough	8.3	5.6	2.1		
		As I like	85.3	7.7			1.9
		Too soft	5.7	6.2	1.5		
	Mouthfeel	Too smooth	5.7	5.8	1.9		
		As I like	87.0	7.7			1.9
		Rough	6.7	5.9	1.8		
	Taste	Not sweet enough	19.7	6.0	1.8		
		As I like	78.3	7.8			1.8
		Too sweet	1.3	6.8	1.1		
	Smell/aroma	Not enough aroma	23.0	6.0	1.8	< 0.0001	
		As I like	75.7	7.9			1.8
		Too much aroma	0.7	7.0	0.9		

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Table 4. Frequency of citations of the quality characteristics by consumers ($n = 300$)

Varieties	Nakitembe	Kibuzi	NARITA 17	NARITA 4
Easy to digest	127 a	112 a	85 b	50 c
Not attractive	15 c	28 c	106 b	160 a
Appealing/attractive	204 a	199 a	94 b	52 c
Mixed colors	20 c	24 c	65 b	89 a
No smell	25 b	34 b	90 a	111 a
Cools quickly	19 c	46 b	63 b	148 a
Moldable	218 a	207 a	155 b	97 c
Flat taste	36 b	34 b	69 a	79 a
Pale yellow	35c	39c	86b	123a
Mild sugary taste	10 a	11 a	16 a	7 a
Watery	4 b	4 b	33 a	1 b
Blackish	1 b	4 b	17 a	19 a
Not compact (crumbles on plate)	4 b	14 b	15 b	61 a
Sap like taste	19 b	24 b	64 a	68 a
Hardness	13 b	26 b	21 b	143 a
Brownish	1 a	2 a	5 a	7 a
Sticky between fingers	105 b	85 c	138 a	65 c
Uniform/even texture	217 a	200 a	114 b	53 c
Soft	249 a	232 a	194 b	98 c
Does not harden quickly	208 a	168 b	123 c	60 d
Smooth mouthfeel	258 a	215 b	152 c	90 d
Good matooke taste	234 a	220 a	141 b	93 c
Deep yellow color	185 a	180 a	73 b	37 c
Good matooke smell	214 a	200 a	132 b	90 c
Overall liking	7.45	7.09	5.68	4.99

Values in the same row with the same lowercase letters do not differ at $P < 0.05$ for Cochran's Q test.

regarded as relatively too soft. Regarding mouthfeel (Fig. 1C), consumers indicated that NARITA 4 was rough. NARITA 17 showed a similar performance to that of Kibuzi, whereas a minority of consumers liked NARITA 4 as it is.

Penalty analysis was conducted[41] to understand the relationship with JAR scores and consumer satisfaction degree scores. Results indicated that Kibuzi was penalized for being 'not sweet enough' and 'not enough aroma' by 26% and 25% of the consumers, respectively. The mean drops are significantly different from 0, and so is the overall penalty (Table 3). NARITA 17 was penalized by 'too light', 'too soft', 'not sweet enough' and 'not enough aroma'. Overall liking of NARITA 4 was penalized by more than 50% of consumers for all sensory attributes namely, 'too light', 'not soft enough', 'rough', 'not sweet enough' and 'not enough aroma'. Nakitembe was only penalized for having 'not enough aroma'. Nakitembe and Kibuzi, which were most preferred in terms of overall liking were also least penalized compared to NARITA 17 and NARITA 4.

The results of the CATA test showed that the most important characteristics, as indicated by the number of citations, were soft by touch, smooth mouthfeel, good matooke taste, moldable, good matooke smell, uniform texture, delayed hardening, attractive and deep yellow color. A comparison of the list of characteristics of the different matooke genotypes are presented in Table 4. The genotypes that have the most citations for the most liked characteristics were Nakitembe, Kibuzi and NARITA17. Significant differences for the most liked characteristics were observed between the landraces and hybrid genotypes (Table 4).

Significant differences were also observed between landraces and improved hybrids regarding the most relevant traits (Table 4). For these traits, Nakitembe and Kibuzi were always significantly better than NARITA 17 (the best of the two hybrids). For some traits of intermediate relevance based on number of citations (hardness by touch and time to cook), there were no significant differences between Kibuzi and NARITA 17.

Preference mapping of the sensory characteristics

PCA was conducted using the estimated means for the sensory characteristics of the steamed matooke. The first two dimensions described 99.3% of the variability. The first dimension (F1) confirmed that most of the preferred characteristics (smooth mouthfeel, nice smell, deep yellow, good matooke taste and uniform texture) are associated with the local genotypes Nakitembe and Kibuzi. Meanwhile, the second dimension (F2) was characterized by undesirable characteristics (sap-like taste, no smell, mixed color, not attractive, pale yellow, cools quickly and hard food) that are associated with the hybrids (Fig. 2A). These relationships can be clearly seen on a bi-plot of correspondence analysis, which show associations between the type of steamed matooke product and product characteristics (Fig. 2B).

Laboratory-based evaluation for QDA

Whereas sensory-based findings are presented above, here, instrumental and laboratory-based panellist analyses are described. Samples were evaluated by 12 panelists at the laboratory for quantitative indicators for their liking (Table 5). The results show that there is a significant difference between Nakitembe

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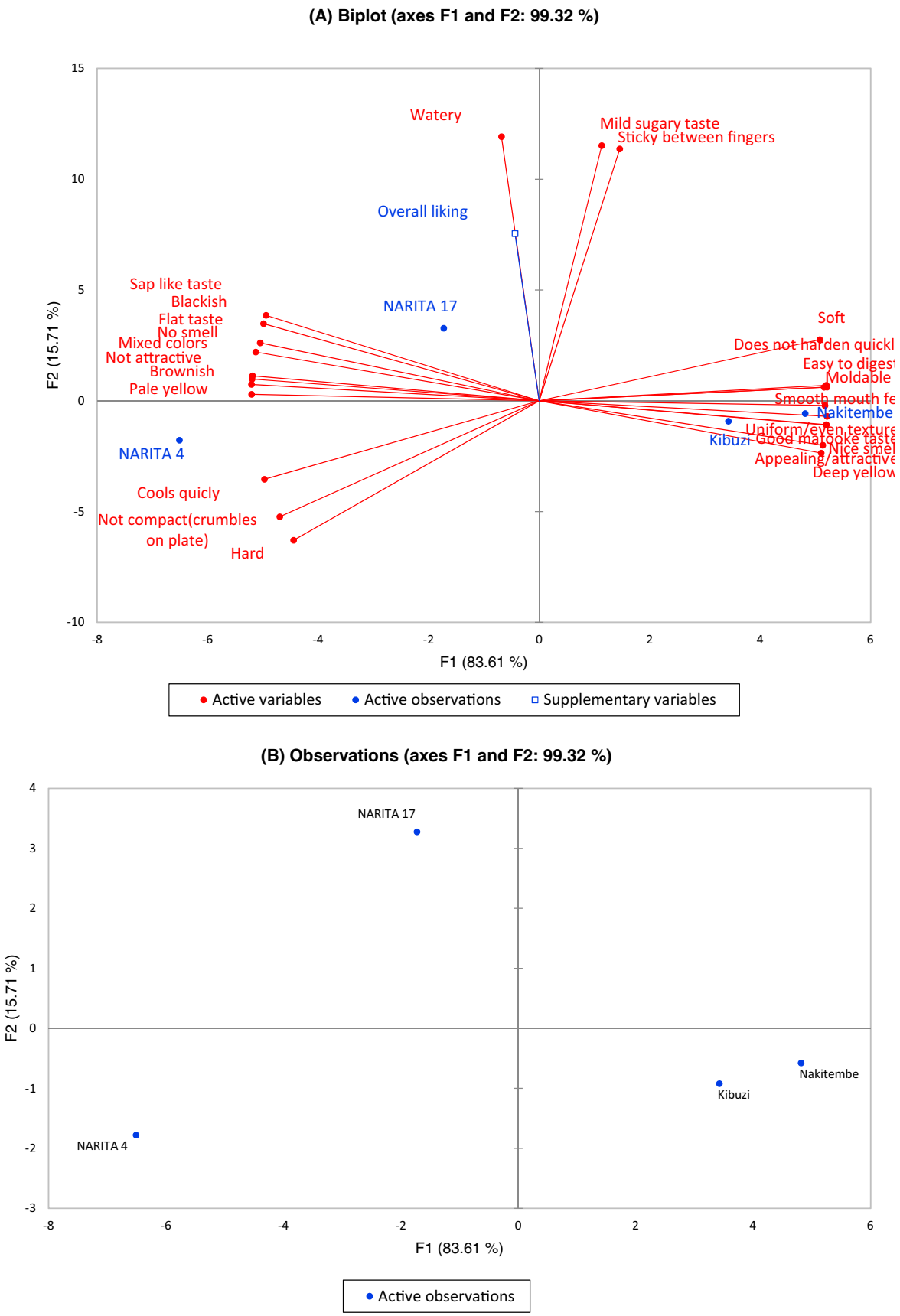

Figure 2. Graphical representation of the sensory characteristics of steamed matooke samples from consumers. (A) Biplot based on the PCA results from sensory analysis on steamed matooke consumers liked. (B) External preference mapping based on the results of the PCA. The axes represent the first (F1 dimensions) and the second (F2 dimensions) of the PCA performed on the results from the sensory analysis.

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Table 5. Mean scores from panellists for sensory attributes of steamed matooke

Descriptors	NAKITEMBE	KIBUZI	NARITA 17	NARITA 4
Yellow	9.00 a	7.33 b	6.78 bc	5.67 c
Homogeneity of color by sight	9.33 a	8.11 ab	6.78 bc	5.67 c
Firmness by mouth	2.00 a	3.11 a	2.33 a	3.89 a
Moistness by mouth	7.00 a	6.56 a	6.67 a	5.00 a
Smoothness by mouth	9.00 a	5.67 b	7.78 a	7.56 a
Hardness by touch	2.33 b	3.67 ab	2.56 b	5.00 a
Moldability by touch	9.56 a	8.56 a	9.00 a	6.78 b
Stickiness by touch	4.44 a	5.56 a	5.89 a	4.33 a
Sweetness	2.00 a	0.89 ab	1.22 ab	0.33 b
Astringency	0.67 a	1.11 a	0.56 a	0.89 a
Sourness	0.44 a	1.00 a	0.67 a	0.56 a
Matooke aroma	8.89 a	7.33 ab	8.11 ab	6.78 b

Values in a row followed by different lowercase letters represent significant differences ($P < 0.05$).
Sensory descriptor scoring scale according to Nowakunda *et al.*[35]

and hybrids in terms of color (Table 5). The hybrids are not significantly different from local varieties in terms of textural characteristics such as firmness, moisture, moldability (apart from NARITA 4) and smoothness (apart from Kibuzi) and stickiness, whereas, in terms of the taste, panellists rated hybrid NARITA 17 taste characteristics such as sweetness, astringency, sourness and aroma not significantly different from local varieties (Table 5).

Potential of the quantitatively assessed quality indicators to predict consumer characteristics

The PCA of the textural, color and matooke taste attributes from consumers (qualitatively assessed indicators) was integrated with the results from the laboratory parameters to determine the potential of QDA to assess consumer preferred characteristics. This explained 91.3% of the total variability. Principal component 1 (PC1) explains 73.3% and PC2 explains 17.97% of the variation (Fig. 3). The results revealed that color characteristic as assessed by the consumers is strongly associated with the laboratory assessed color indicators (Fig. 3). With respect to texture, the consumers assessed textural characteristics (namely moldability, smoothness in the mouth and softness by touch) were also strongly correlated with the quantitatively assessed textural indicators (Fig. 3). Matooke taste as assessed by the consumer panel is strongly associated with smooth texture and deep yellow color, which were the characteristics associated with landraces in the laboratory sensory assessment (Fig. 3).

Correlation analysis (Table 6) revealed strong positive correlations between the consumer assessed characteristics, hardness by touch, softness by touch and yellowness, as well as quantitative laboratory characteristics (moldable, hardness by touch, softness by touch and yellowness) of the steamed matooke. This confirms that the consumer results were consistent with the laboratory sensory results, indicating that QDA could easily select a suitable/preferred variety for consumer needs.

DISCUSSION

Smallholder banana farmers produce specific varieties that meet a range of criteria, including adaptation to production constraints (e.g. pests and diseases, soil conditions), yield potential, quality and compatibility with overall farming system management. Therefore, the final product might not be what is most demanded in the market. Consumers of matooke have specific characteristics that they desire,[42] and failure to supply what is needed may give banana traders a hard time to engage in the market and result in unmet demand. The present study revealed that consumers preferred steamed matooke from landraces Nakitembe and Kibuzi, whereas those from hybrids NARITA17 and NARITA 4 were the least preferred, particularly the later. The steamed matooke products from these landraces were characterized by liked attributes including color, softness by touch and mouthfeel. The yellow color of the steamed matooke product influences consumers' opinions of its taste and softness by touch, as well as a willingness to choose the variety with that particular color. Matooke genotypes that lack yellow color are often rated inferior to the landrace varieties and rejected.[43–45] Consumers of steamed matooke associate yellow color with good taste and, if the product's color does not match consumer expectation, consumers will regard the product to taste differently and substandard.[23] This explains, along with several other relevant traits, the wide differences in overall liking scores between the hybrids and landraces in the present study. Landraces (Nakitembe and Kibuzi) can therefore be used as references to define the biochemical indicators of color and texture. In studies by Kuntashula *et al.*[46] and Marimo *et al.*,[47] consumers demonstrated preference for local varieties in terms of taste and color and these were frequently cited as the major reasons for their survival in the market and on farmers' fields.

The present study demonstrates that consumer preferences for steamed matooke are driven by several preferred product characteristics such as deep yellow color, good matooke taste and smell. Often, each characteristic individually contributes to the product choice (Table 3). This suggests that appropriate testing methodologies should be applied in order to evaluate varieties that meet consumer demands.

The results showed a large gap between steamed matooke product from the landrace varieties and the matooke hybrids regarding textural attributes (softness by touch, hardness, moldability, smoothness in the mouth and uniform/even texture). This highlights the importance of texture as a selection criterion. This result is similar to past studies that identified texture, as well as the related mouthfeel of a product, as playing an essential role

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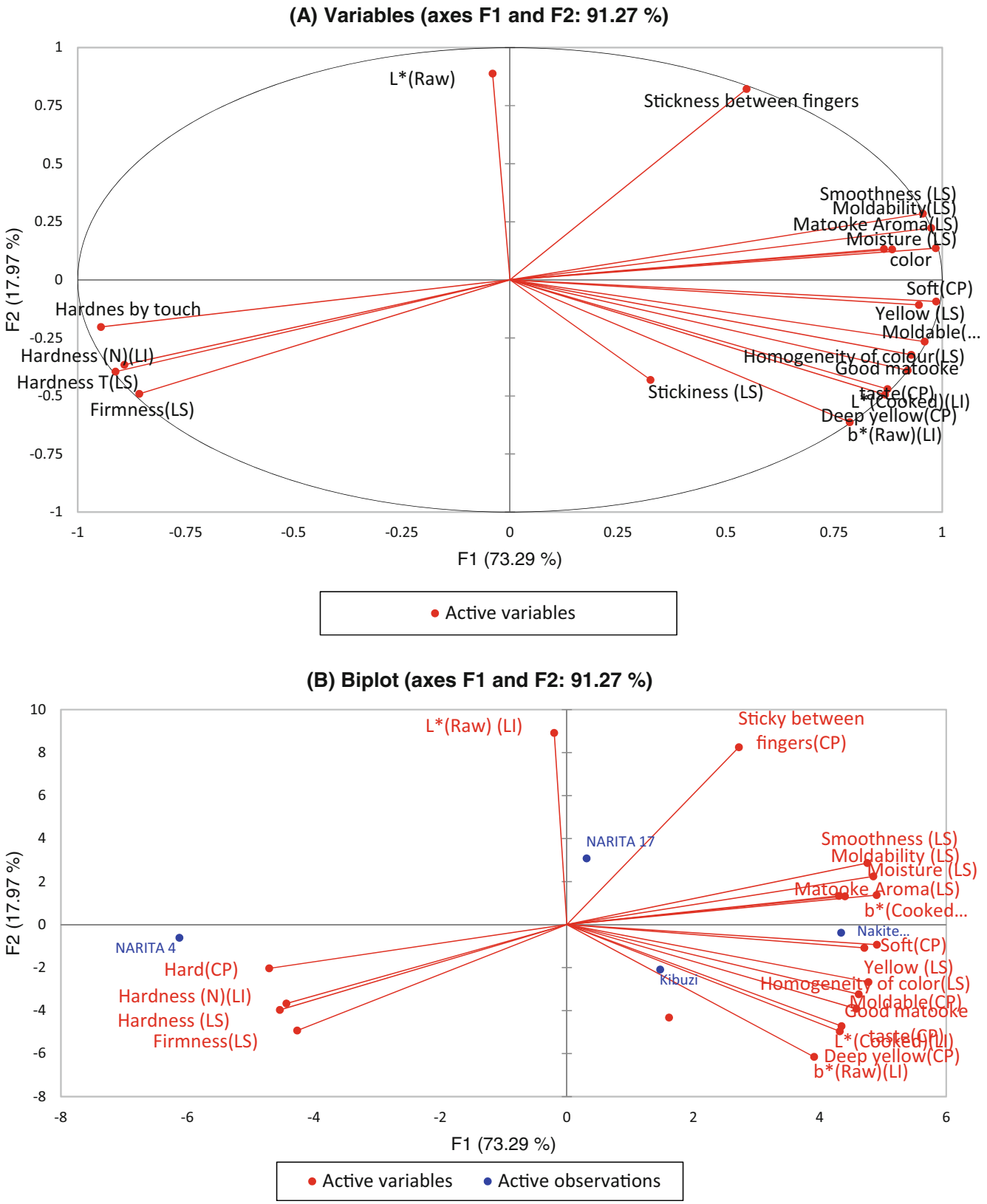

Figure 3. Representation of samples from both the sensory characteristics of steamed matooke samples from consumers and laboratory assessed parameters. (A) Biplot based on the PCA of results from sensory analysis on steamed matooke consumers liked with the laboratory assessed parameters. (B) External preference mapping based on the results of the PCA. The axes represent the first (F1) and the second (F2) dimensions of the PCA performed on the results from the sensory analysis. CP, consumer perception; LS, laboratory sensory; LI, laboratory instrument.

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Table 6. Correlation between descriptive sensory attributes steamed matooke for consumer assessed and quantitative characteristics

Descriptors	Moldable (CP)	Hardness (CP)	Stickiness (CP)	Soft (CP)	Yellow (CP)	Yellow (LS)	Smoothness M(LS)	Hardness T(LS)	Moldable (LS)	Stickiness T(LS)	Hardness (N)(LI)
Moldable (CP)	**1.00**										
Hardness (CP)	–0.88	**1.00**									
Stickiness (CP)	0.32	–0.72	**1.00**								
Soft (CP)	0.98	–0.95	0.48	**1.00**							
Deep yellow (CP)	0.97	–0.73	0.08	0.91	**1.00**						
Yellow (LS)	0.91	–0.81	0.38	0.90	**0.86**	**1.00**					
Smoothness M(LS)	0.83	–0.94	0.75	**0.90**	0.68	0.90	**1.00**				
HardnessT(LS)	–0.76	**0.92**	–0.81	–0.85	–0.59	–0.85	–0.99	**1.00**			
Moldable T(LS)	**0.87**	–0.96	0.71	0.94	0.74	0.90	0.99	–0.98	**1.00**		
Stickiness T(LS)	0.51	–0.43	–0.04	0.48	0.5436	0.09	0.12	–0.04	0.21	**1.00**	
Hardness (N)(LI)	–0.73	**0.85**	–0.75	–0.81	–0.58	–0.89	–0.98	0.99	–0.96	0.09	**1.00**

CP, consumer perception; LS, laboratory sensory; LI, laboratory instrument. N, Newtons.

in how consumers evaluate a product.[48,49] In steamed matooke, texture influences not only tactile, but also visual attributes such as uniformity or evenness after mashing, which affects the appearance and consequently the acceptability.

The present study has significantly contributed to understanding a product profile that breeders should aim for. It has demonstrated that the laboratory-based method can be used to predict the consumer acceptance of the new matooke genotypes. The strong associations observed between laboratory-assessed and consumer characteristics (moldable, hardness by touch, softness by touch and yellowness) (Fig. 3 and Table 6) suggest that instrumental approaches have the advantages of product evaluation compared to large scale consumer sensory panels. The result of a study by Benjamin *et al.*,[50] investigating the use of sensory and instrumental measurements on standard and crisp texture of the southern highbush blueberries (*Vaccinium corymbosum* L. interspecific hybrids), confirmed that these approaches are advantageous because of their reproducibility, low cost, rapid generation of data and technical ease compared to the use large scale consumer sensory panels.[24] When investigating important sensory attributes that affect consumer acceptance of sorghum porridge, Aboubacar *et al.*[51] reported that the gel consistency, a laboratory measured attribute, showed some association with consumer rating for porridge texture. Also, the porridge color as assessed by consumers correlated significantly with Hunter *L* and *E* values. The strong correlations observed between textural and color properties both in the laboratory and the sensory meant that what consumers want can be predicted by laboratory results, indicating that a combination of sensory and instrumental methodologies comprises an effective and efficient variety selection method for technology adoption.

AUTHOR CONTRIBUTIONS

KA was responsible for the conception and design of the study. AB was responsible for the design of data collection tools. KA, MA, SK, EK, ET, YM, MGN and LT were responsible for acquisition of data. KA, PM, EK, YM, LT, PBS and KN were responsible for analysis and interpretation of data. PM, RT, MA, YM, LT, PBS, DD, WT and KN were responsible for drafting the manuscript. PM, AB, RT SK, ET, MGN and WT were responsible for manuscript editing. DD and KN were responsible for revising the manuscript critically for important intellectual content.

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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 available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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ETHICAL STATEMENT

This study was approved by the National Research Ethics Committee in Uganda. Research teams obtained ethical approval prior to the fieldwork. Informed written consent from sensory panellists and from consumers participating in this study were obtained prior to conducting any research activities. The research process respected the rules of voluntary participation and anonymity. Participants were told that they could stop the interview at any point. Food samples were prepared according to good hygiene and manufacturing practices. Before starting any of the activities, informed consent was sought from all participants explaining to them their rights as research participants in the local language. An approval consent was provided with approval number MAKSS REC 12.19.364.

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