Research Article

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Decision tree scoring system to guide selection for consumer preference in sweetpotato breeding trials

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Abstract

BACKGROUND: Previously, a lexicon and protocol for quantitative descriptive analysis (QDA) was established for the Uganda sweetpotato breeding program. The implication of QDA scores for priority sensory attributes on consumer preference should be determined to interpret results efficiently and make decisions effectively. The present study aimed to develop a gender-responsive decision tree to obtain an overall sweetpotato eating quality score to facilitate demand-led targeted breeding selection. It focused on Kamuli and Hoima districts (Uganda) and uses pre-lease advanced clones ('NKB3', 'NKB105', 'NKB135', 'D11' and 'D20'), released varieties ('NASPOT 8' and 'NAROSPOT 1') and landraces ('Muwulu-Aduduma', 'Umbrella').

RESULTS: Including boiled sweetpotato sensory characteristics, namely mealy, sweet taste, sweetpotato smell, firm and not fibrous, in breeding design would benefit end-users, especially women given their role in varietal selection, food preparation and marketing. 'D20', 'NASPOT 8' and 'NAROSPOT 1' were most liked in both districts. 'NKB3' and 'D11' were the least liked in Hoima, whereas 'Muwulu-Aduduma' was the least liked in Kamuli. There was a positive correlation between color and overall liking ($r^2 = 0.8$) and consumers liked the color (average rating ≥ 6 on a nine-point hedonic scale) of all genotypes. Threshold values (average rating on 11-point scales) for consumer acceptability were identified (sweet taste = 6, sweetpotato aroma and flavor = 6, firmness = 3, and mealiness = 4). A regression decision tree tool was created to calculate an eating quality selection index when screening lines in breeding programs using the values.

CONCLUSION: Decision trees that include consumer needs and gender considerations would facilitate demand-led breeding and make varietal selection in sweetpotato breeding programs more effective.

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

Keywords: quality control; efficient breeding; selection index; RTB crops

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INTRODUCTION

Sweetpotato [*Ipomoea batatas* (L.) Lam] is the second most important root crop in sub-Saharan Africa (SSA), as indicated by its high production and role in food security.[1] However, production and productivity in SSA is constrained by various biotic and abiotic stresses.[2-4] Breeding programs in Uganda have successfully developed new varieties with improved agronomic characteristics and nutritional value.[5-8] Recognizing that adoption rather than release was a better indicator of breeding efficiency,[9] the previously centralized breeding approach of the staple was decentralized by transitioning to a participatory sweetpotato breeding model.[10,11] Nonetheless, breeding objectives still emphasized farmers' agronomic needs and biofortification, thus sustaining suboptimal adoption of released varieties[12] as a result of unmet eating quality needs of other actors, particularly consumers.

Consumer preference for a variety is often influenced by eating quality, especially sensory characteristics,[13] which need to be considered when breeding new varieties.[14] Moreover, besides individuals who eat sweetpotato, other value chain actors also attach an economic value to the sensory quality of sweetpotato.[15] In their study to generate a product profile focused on consumer needs, Mwanga *et al.*[16] found that Ugandans preferred sweetpotatoes with varying hues of bright uniform colors, good smell, sweet taste, firm, mealy and non- fibrous texture. Another study showed that sweet taste, but not color, was an important driver of sweetpotato variety preference among Ugandan consumers.[17] In the same study, consumers indicated softness, mealiness, high dry matter and good aroma as additional desirable characteristics, whereas wateriness and fibrousness were undesirable characteristics.

Unfortunately, consumers express their needs and perceptions in a vague[18] and subjective manner. However, it is imperative that breeders understand them and design innovations to incorporate these requirements. For example, consumer preferences,[16,17] such as 'good taste', 'good appearance', 'attractive color' and 'bad smell' were unspecific, and contradictory because 'sweet taste' and 'soft' were desirable, but 'too sweet' and 'too soft' were undesirable. Clearly, for some characteristics, preference is based not on the presence of an attribute but rather its intensity. Moreover, perceptions of varietal attributes differ among women and men along the sweetpotato value chain.[15,19,20] The results of these studies, although useful in exploring consumer sensory preferences, could not be effectively integrated in breeding programs. The present study uses key quality traits ranked in previous studies for sweetpotato in Uganda to develop a quality control tool (decision tree) that will feed into the economic selection index tool for sweetpotato breeding programs.

Descriptive sensory analysis (DSA) is a reliable method for measuring the nature and magnitude of human sensory perceptions.[21] Quantitative descriptive analysis (QDA) is a DSA method involving rating of different sensory attributes on a defined scale by a trained group of individuals referred to as a panel.[22] A lexicon and protocol for QDA to facilitate routine sensory profiling of sweetpotato traits by the breeding program in Uganda has been developed.[23] However, it is currently difficult for breeders to implement selections among genotypes by drawing inferences from the numerical output of QDA, thus limiting its value to sweetpotato breeders.

A classification decision tree guiding breeders on inferences to be drawn from different sensory scores when selecting edamame genotypes for sensory quality and consumer preferences has been developed.[24] Although it indicated how to construct an eating quality-based decision making or quality control tool for breeding selection, the study did not consider gender aspects. Yet gender issues impact producers and growers of sweetpotato in Uganda,[25] and women influence new varietal selection and adoption of this crop.[26,27] It is therefore important to include a step where gender implications are formally and systematically queried when defining breeding objectives and trait targets.[25] Also, the classification decision tree for edamame did not have to be aligned with another selection index. An economic selection index tool that consolidates all sweetpotato traits that are important for the various value chain actors including those concerning production, nutrition and eating quality has been developed.[15] It proposes different weights for traits associated with productivity (such as yield), resilience (e.g. disease resistance) and root quality (e.g. root size and sensory quality) breeding outputs. Therefore, a decision tree for sweetpotato breeding in Uganda requires two important modifications to the one established for edamame[24]: (1) gender consideration and (2) integration into the economic selection index.

MATERIALS AND METHODS

Gender assessment of sweetpotato varietal characteristics

The present study builds on previous work[16,28] that developed and refined the first sweetpotato product profile. As a follow-up, the G+ Product Profile Query Tool (G+PP)[29,30] was applied to assess the potential positive and negative impact that breeding for sensory characteristics could have on women and men. The tool was programmed in CSPro (United States Census Bureau; http://www.census.gov/ipc/www/cspro) and participants analyzed the characteristics individually on tablets. Application of the tool involved a purposively selected multidisciplinary team comprising three food scientists, five sweetpotato breeders, one gender specialists and two farmers.[31] The gender specialist separately reviewed the evidence report and priority characteristics afterwards.

Specifically, the analysis focuses on the effect of including sensory characteristics in the product profile on four aspects of gender (in)equality: drudgery and time poverty, control over critical assets and resources, access to and control over purchased/external inputs, and access to and control over sharing of benefits.[32] Using the (G+PP) tool, the priority characteristics evaluated for steamed sweetpotato were mealy, sweet taste, good sweetpotato smell, firm and not fibrous. The team reviewed the gender roles related to production, marketing and utilization, and their perceived consequences of breeding for these sensory characteristics. These characteristics were assigned a qualitative gender impact score on 'Positive benefit' and 'Do no harm' scales[31] according to six-question items each, first individually then by consensus. The qualitative gender impact scores and descriptions are shown in Table 1.

Table 1. G+ product profile query tool scales, scores and their relative meaning

Scale	Gender impact score	Implication
'Positive benefit'	0 (Neutral)	No significant benefit
	+1 (Nice to have)	Moderate benefit
	+2 (Required)	Considerable benefit
'Do no harm'	0 (Neutral)	No significant harm
	−1 (Amend or avoid)	Moderate harm
	−2 (Reject)	Considerable harm

Sensory evaluation of sweetpotato samples

Sampling and sample collection

The sensory evaluation was conducted as part of on-farm trials. Genotypes of varying flesh color (Table 2) including improved and local clones, as well as checks were grown by farmers in two study districts in 2022. The two districts are in different agro-ecological zones. The genotypes 'D11', 'D20', 'Muwulu-Aduduma', 'NAROSPOT 1', 'NASPOT 8', 'NKB3' and 'NKB105' were collected from both districts, whereas 'Umbrella' was collected in Hoima, and 'NKB135' in Kamuli. For each genotype, roots sourced from five farmers at the district level were pooled together and samples from the pool used to conduct consumer acceptability tests in each district and descriptive sensory analysis in the laboratory.

Consumer sensory analysis

Sweetpotato roots for consumer evaluation were steamed by women in each district as described in previous work[23] following common household cooking practices. In total, 106 (78 women and 28 men) and 99 (33 women and 63 men) residing in Hoima and Kamuli, respectively, who were frequent (several days a month) consumers of sweetpotato aged from 18 to 70 years were interviewed in consumer evaluation surveys. Enumerators were trained to translate the consent form and questionnaire into the common languages spoken in the target communities. Informed consent was sought and obtained from the respondents before administering the questionnaire. Respondents were assigned a unique identification code to protect their personal information. Each respondent was asked to comment about sensory characteristics they liked and disliked about each sample. Respondents were also requested to rate overall-, color- and aroma-liking on nine-point hedonic scales ranging from '1' (dislike extremely) to '9' (like extremely) and anchored at '5' (neither like nor dislike), and sweet taste, firmness and mealiness on five-point just-about-right (JAR) scales anchored at '3' (JAR). Such scales have been used with similar communities in a previous study[16] and the complete questionnaire was presented elsewhere.[23] Upon completion of the interview, the respondents were each given a monetary compensation valued at 5000 Uganda shillings (equivalent to $1.30 USD) to cover their costs of travel to study venue.

Descriptive sensory analysis

Twelve trained panellists rated steamed sweetpotato samples for orange color intensity, uniformity of color, fibrous appearance, sweetpotato aroma, sweetpotato flavor, off-odor, sweet taste, firmness in mouth, crumbliness in mouth, moisture in mass and fibrous texture in Compusense (Academic Consortium, Compusense Cloud, Compusense Inc.; Guelph, ON, Canada). Details about how the panel was set up and trained, lexicon development, and procedure for sample preparation and service have been presented elsewhere.[23] The panellists had previously provided informed consent to participate in the study. They were compensated with a monetary amount equal to 20 000 Uganda shillings per day (equivalent to $5.30 USD) to cover their study participation expenses.

Statistical analysis

G+ product profile analysis

Individual scores/assessments from participants were collated and frequencies analyzed in Excel (Microsoft Corp., Redmond, WA, USA). A final score for the breeding priority traits was reached by consensus following discussion of the preliminary results. In cases where a characteristic was considered to have moderate negative gender implications ('do no harm' = −1), the group also agreed on a possible mitigation strategy. Characteristics with considerable negative gender implications ('do no harm' = −2) were rejected and removed from the final list of priority quality traits (PQTs).

Curation and evaluation of sensory data

Data were scanned to check that each entry was complete and correctly entered. Altogether, 31 cases of incorrectly scored JAR ratings (assigned scores greater than five) were discarded from the Kamuli dataset. Data were processed as previously described.[23]

Descriptive sensory analysis data were processed as described by Nakitto *et al.*[23] The panel average ratings for each attribute were calculated and analyzed using principal component analysis (PCA) by covariance in XLSTAT (https://www.xlstat.com). Attributes such as off odour and fibrousness, which had small contribution to the variation of the samples, were not included in the final PCA.

Comparisons between consumer sensory analysis and descriptive sensory profiles

In Excel, correlations between liking measures and corresponding average ratings of sensory descriptors by the trained panel were investigated using scatter plots and linear regression. The r^2

Table 2. Morphological characteristics of sweetpotato genotypes used in the study by district

Genotype	Skin color	Flesh color	District	Release status
Improved clones				
'D11'	Pink/cream	Orange	Hoima and Kamuli	Pre-release, Improved
'D20'	Purple-red	Orange	Hoima and Kamuli	Pre-release, Improved
'NKB 3'	Brown	Orange	Hoima and Kamuli	Pre-release, Improved
'NKB 105'	Cream	Orange	Hoima and Kamuli	Pre-release, improved
'NKB 135'		Orange	Kamuli only	Pre-release, Improved
Local clones				
'Muwulu-Aduduma'	Cream	White	Hoima and Kamuli	Landrace
'Umbrella'	Purple red	Yellow	Hoima only	Landrace
Checks				
'NAROSPOT 1'	Purple-red	Yellow	Hoima and Kamuli	Released, Improved
'NASPOT 8'	Pink/red	Yellow-orange	Hoima and Kamuli	Released, Improved

values were used as indicators of the strength of relationships between consumer preference by location and the descriptive sensory attribute. Because all samples had an average overall liking of at least six indicating that they were all liked albeit to varying degrees in Kamuli, data from Kamuli were excluded from this step and subsequent ones (establishing thresholds and development of decision tree).

Establishing thresholds for preferred quality traits

Threshold values indicating consumer preference were established following the method used by Nakitto *et al.*[23] In brief, first, graphs of overall liking and consumer preference were plotted to identify the frequency of 'JAR' designations or liking scores associated with a minimum overall liking of 6, which corresponds to 'like slightly'. For color and aroma, overall liking was plotted against color and aroma liking scores. Then, graphs of aroma liking and color liking were plotted separately against descriptive sensory attributes related to color and aroma, and the level of the attribute corresponding with the value identified in the first step was calculated from the best-fit equations. For sweetness, firmness and mealiness, overall liking was plotted against the frequency of responses to the JAR questions. Then, graphs of JAR frequency of responses and descriptive sensory attributes related to sweet taste, firmness and mealiness were plotted separately. The descriptive sensory attribute intensities corresponding with the values identified in the first step were calculated from the resulting best-fit equations.

Development of decision tree

A regression decision-tree scoring system based on whether a product satisfies the established PQT threshold or not was created to make the tool compatible with the economic selection index tool for sweetpotato. This tool was designed to guide calculation of an eating quality score as follows:

(1) The average ratings for the sensory attributes from QDA are first rounded off to the nearest significant number.
(2) If the rating of a sample is equal to or greater than the proposed threshold value, a score of 1 is assigned to the sample for that priority quality trait.
(3) If the rating of a sample is less than the proposed threshold value, a score of 0 is assigned to the sample for that priority quality trait.
(4) Total eating quality score would be the sum of all the scores for each of the priority quality trait.

The tool was applied on the samples used in the study and on a set of archived data from trained panel ratings of 59 sweetpotato genotypes harvested from advanced yield trial trials in the 2022A season.

RESULTS

Gender and livelihoods assessment of priority sweetpotato characteristics at different processing stages

The results from the gender and livelihoods assessment of the characteristics showed the importance of eating quality characteristics. All eating quality characteristics (mealy, sweet taste, good sweetpotato smell, firm and not fibrous) were assigned 'neutral' on the 'do no harm' scale indicating that they posed no significant socio-economic disadvantage for women. On the 'positive benefit' scale, they were assigned +2 (required) showing that the characteristics had considerable benefit for both men and women. This implied that these characteristics were essential and needed to be included in the product profile.

Consumer preference for sweetpotato genotypes by location

Overall liking ranged from 5 to 7 in Hoima and 6 to 8 in Kamuli as shown in Table 3. In both districts, the genotypes rated highest for overall liking were 'D20' (Hoima = 7, Kamuli = 8), 'NASPOT 8' (Hoima = 7, Kamuli = 8) and 'NAROSPOT 1' (Hoima = 7, Kamuli = 7) indicating that they were most liked. In Hoima, 'NKB3' and 'D11' were the least liked with overall liking score of 5 each, whereas 'Muwulu-Aduduma' and 'NKB3' were least liked in Kamuli with average overall liking of 6. The flesh color of 'D20', 'NAROSPOT 1' and 'NASPOT 8' were well-liked in both Hoima (color liking = 8, 7 and 7, respectively) and Kamuli (color liking = 8, 7 and 7, respectively).

The results from analysis of JAR questions are presented in Fig. 1. At least 50% of consumers in Kamuli perceived all the genotypes tested to be JAR in sweetness, firmness and mealiness, except 'NKB3' and 'Muwulu-Aduduma', where a bigger proportion of consumers did not perceive them to be JAR mealy. By contrast, consumer preference for genotypes with respect to these characteristics in Hoima varied widely by genotype and characteristic. Less than 50% consumers in Hoima found the sweetness intensity of 'NKB3' and 'D11' to be JAR. Also, a bigger proportion of consumers in Hoima did not perceive 'NKB3', 'NKB105' and 'Muwulu-Aduduma' to be JAR firm and mealy compared to Kamuli.

Sensory profiles of sweetpotato genotypes established by sensory panel

The average ratings for the sensory attributes of the sweetpotato genotypes are presented in the Supporting information (Table S1). The sensory profiles of the sweetpotato established by the trained sensory panel for genotypes used in this study are presented as a PCA plot (Fig. 2). The first three principal components explained 97% of the total variation. The first principal component, F1, separates genotypes by orange color intensity, uniformity of color and moisture in mass. Orange fleshed, more uniform and moist genotypes appear on the right side of plot A whereas those with white, cream and yellow flesh lie on the left side. 'D20' grown in Hoima had color that was more uniform than the same genotype grown in Kamuli. Conversely, roots of 'D11' and 'Muwulu-Aduduma' had a more uniform color in Kamuli than in Hoima. The second principal component, F2, separates genotypes by firmness and crumbliness with firmer and crumblier genotypes on the right and moist ones on the left in plot B. Most soft and less crumbly samples were orange fleshed, except 'Muwulu-Aduduma' which is non-orange. Some orange fleshed genotypes were characteristically firm and mealy, particularly 'D20' and 'NASPOT 8' from both districts, and 'D11' from Hoima. 'D11' from Kamuli was soft unlike the one from Hoima. The third principal component, F3, separates genotypes by sweetpotato flavor and sweet taste. Sweeter genotypes with high sweetpotato flavor are in the top half of plot B, whereas less sweet genotypes with low sweetpotato flavor such as 'NASPOT 8' and 'NKB135' from Kamuli, 'D11' from Hoima appear in the bottom half.

Threshold values of sensory attributes of sweetpotato that influenced consumer acceptability by district

The associations between consumer acceptability measures and overall liking are displayed in Fig. 3. Figure 4 shows relationships between consumer acceptability measures and descriptive sensory attributes rated by a trained panel. Although there was a positive relationship between color liking and overall liking ($r^2 = 0.80$)

Table 3. Variation in mean score of overall liking, color liking and aroma liking rated on nine-point hedonic scales by consumers, among genotypes by location

	Overall liking		Color liking Mean ± SD		Aroma liking	
Genotype	Hoima	Kamuli	Hoima	Kamuli	Hoima	Kamuli
'D11'	5 ± 3 d	7 ± 2 bcd	6 ± 3 b	7 ± 2 ab	5 ± 3 d	7 ± 2 b
'D20'	7 ± 2 a	8 ± 1 a	8 ± 2 a	8 ± 1 a	7 ± 2 a	8 ± 1 a
'Muwulu-Aduduma'	6 ± 2 bc	6 ± 3 e	6 ± 3 b	6 ± 2 d	7 ± 3 ab	6 ± 3 c
'NAROSPOT 1'	7 ± 2 ab	7 ± 2 bc	7 ± 2 a	7 ± 2 bc	7 ± 3 ab	7 ± 2 b
'NASPOT 8'	7 ± 2 ab	8 ± 1 ab	7 ± 2 a	7 ± 2 ab	7 ± 3 ab	7 ± 2 ab
'NKB105'	6 ± 3 c	7 ± 2 bcde	6 ± 3 b	7 ± 2 ab	6 ± 3 bc	7 ± 2 ab
'NKB3'	5 ± 3 d	6 ± 3 de	6 ± 3 b	7 ± 2 cd	6 ± 3 cd	7 ± 2 bc
'Umbrella'	7 ± 3 ab		6 ± 3 b		7 ± 3 ab	
'NKB135'		7 ± 2 cde		7 ± 2 ab		7 ± 2 bc
$P_{variety}$	NS	NS	***	***	***	***
$P_{district}$	***		**		***	

Note: *P* value by ANOVA. Mean separation by Duncan. Values in the same column with different lowercase letters are significantly different.
Abbreviation: NS, not significant.
** $P < 0.01$;
*** $P < 0.001$.

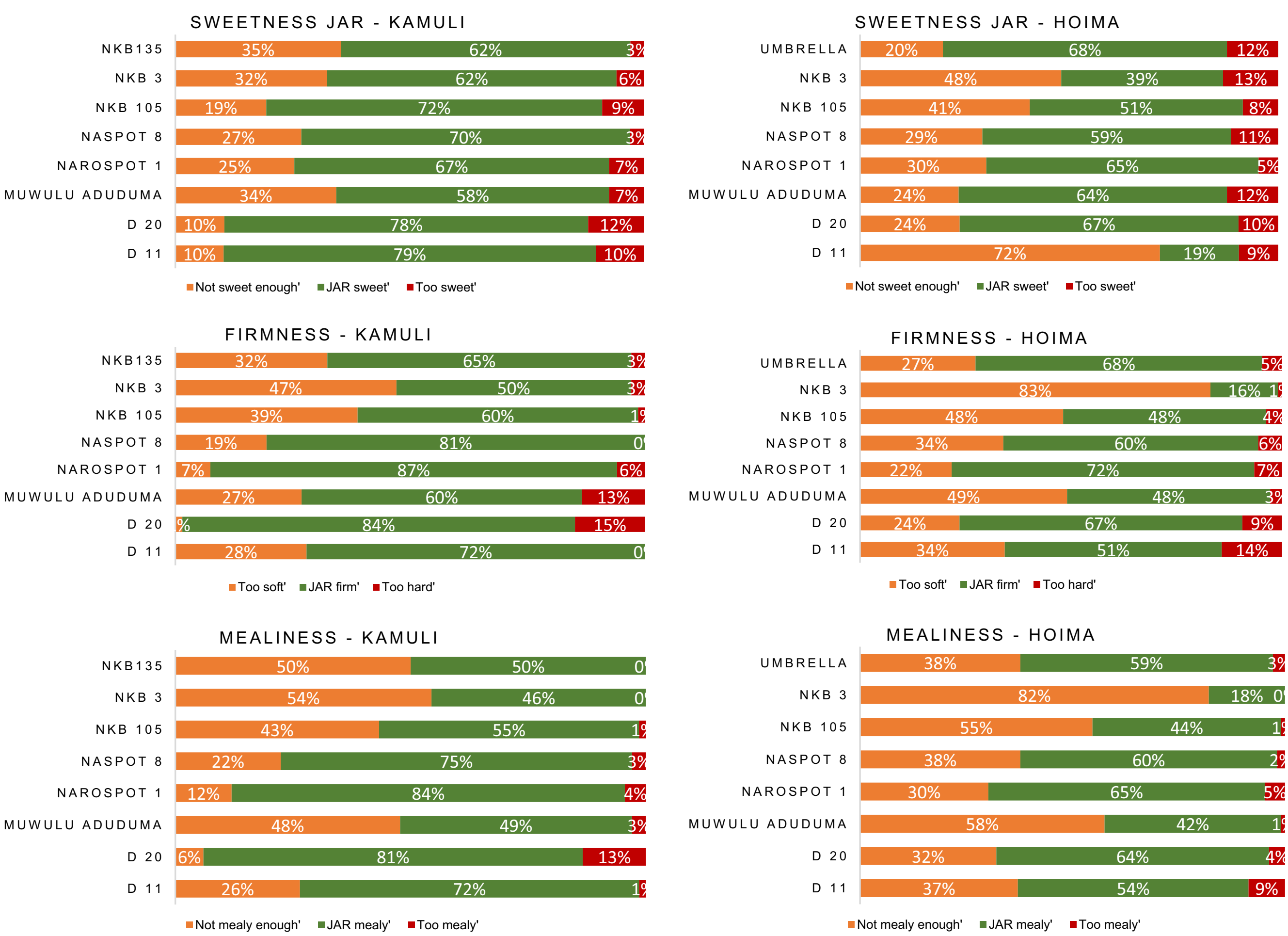

Figure 1. Frequency response (%) to JAR question about sweetness, firmness and mealiness in Kamuli ($n = 67$) and Hoima ($n = 101$).

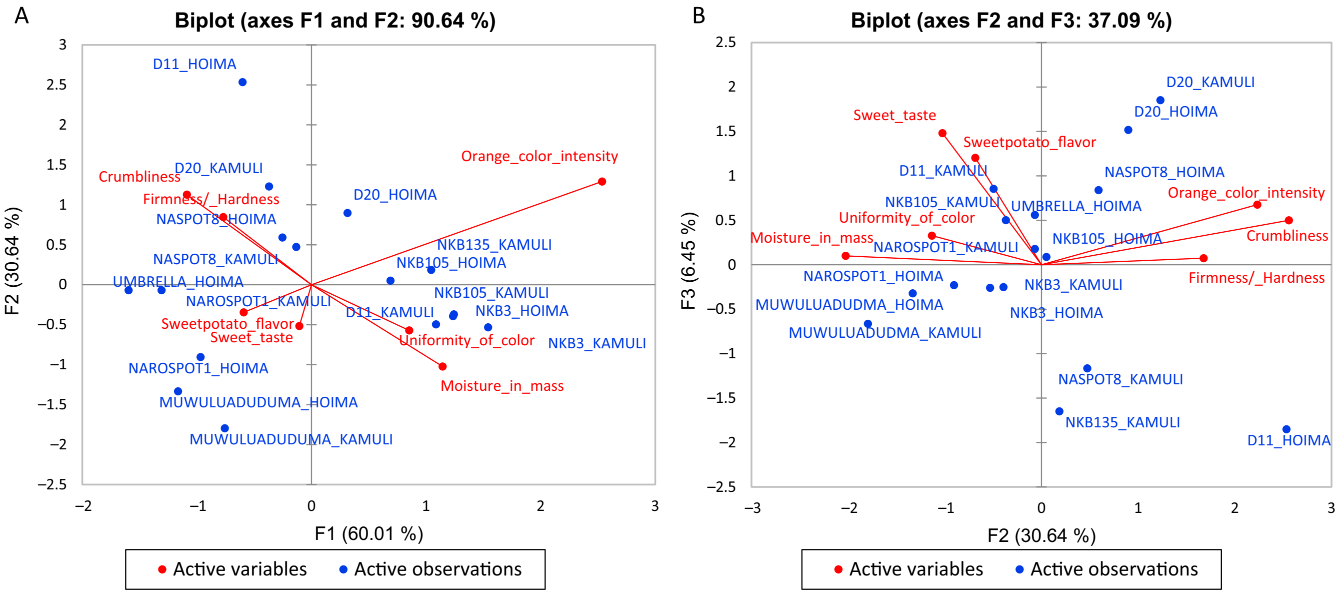

Figure 2. Principal component analysis [(A) F1 *versus* F2 and (B) F2 *versus* F3], separating sweetpotato genotypes according to ratings of the sensory characteristics rated by a trained panel.

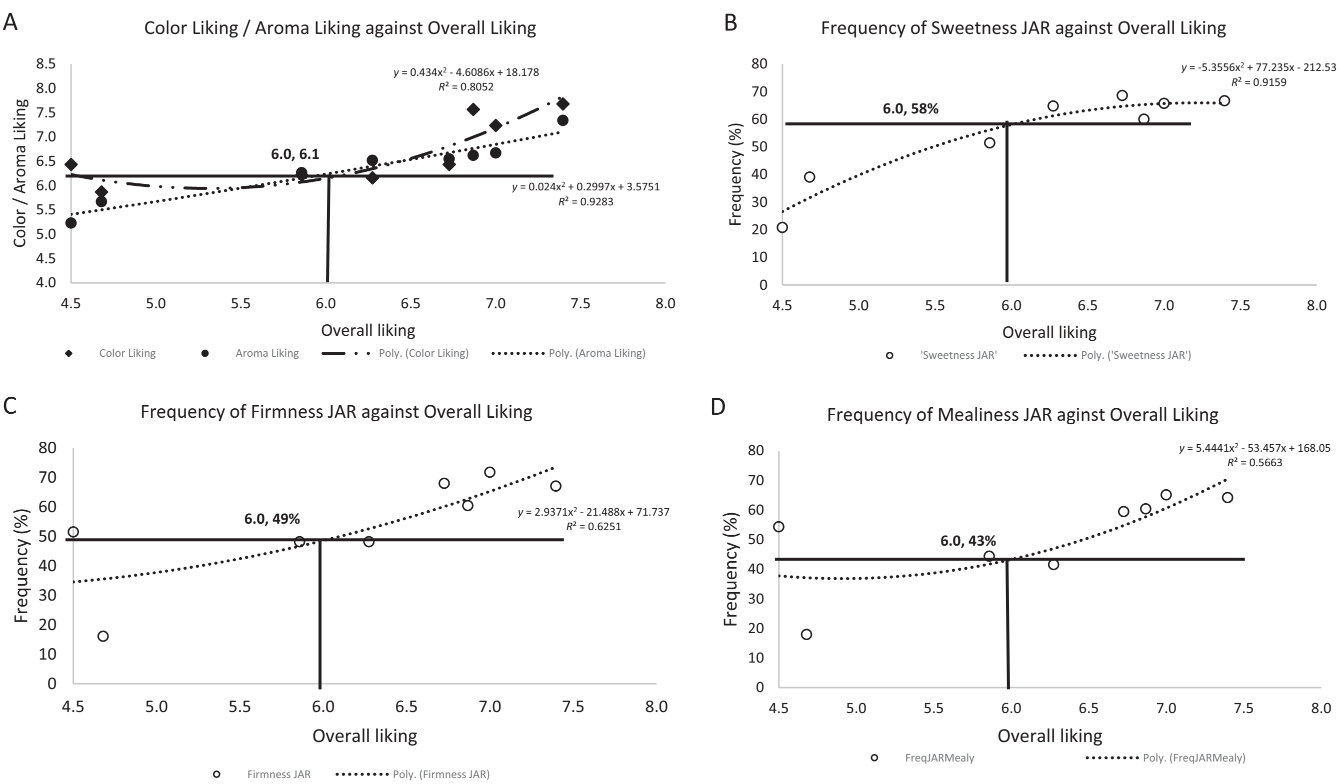

Figure 3. Plots showing relationships between overall liking and consumer acceptability measures for various sensory characteristics [(A) color and aroma liking against overall liking; (B) frequency response to sweetness JAR question against overall liking; (C) frequency response to JAR question on firmness against overall liking; (D) frequency response to JAR mealiness against overall liking] rated by consumers on nine-point hedonic scales and five-point JAR scales; JAR responses reduced to three groups for analysis; intersection of horizontal and vertical lines denotes the point on the graph where overall liking is 6.

(Fig. 3A), all genotypes were rated ≥ 6 for color showing that consumers responded positively to varied color characteristics. Therefore, the thresholds for color attributes rated by the trained sensory panel could not be established in the present study.

Aroma liking was also related to overall liking ($r^2 = 0.93$) and descriptive measures of sweetpotato aroma and flavor had a positive relationship with aroma liking ($r^2 = 0.76$ and $r^2 = 0.90$, respectively). An average aroma liking value of 6.1 corresponded

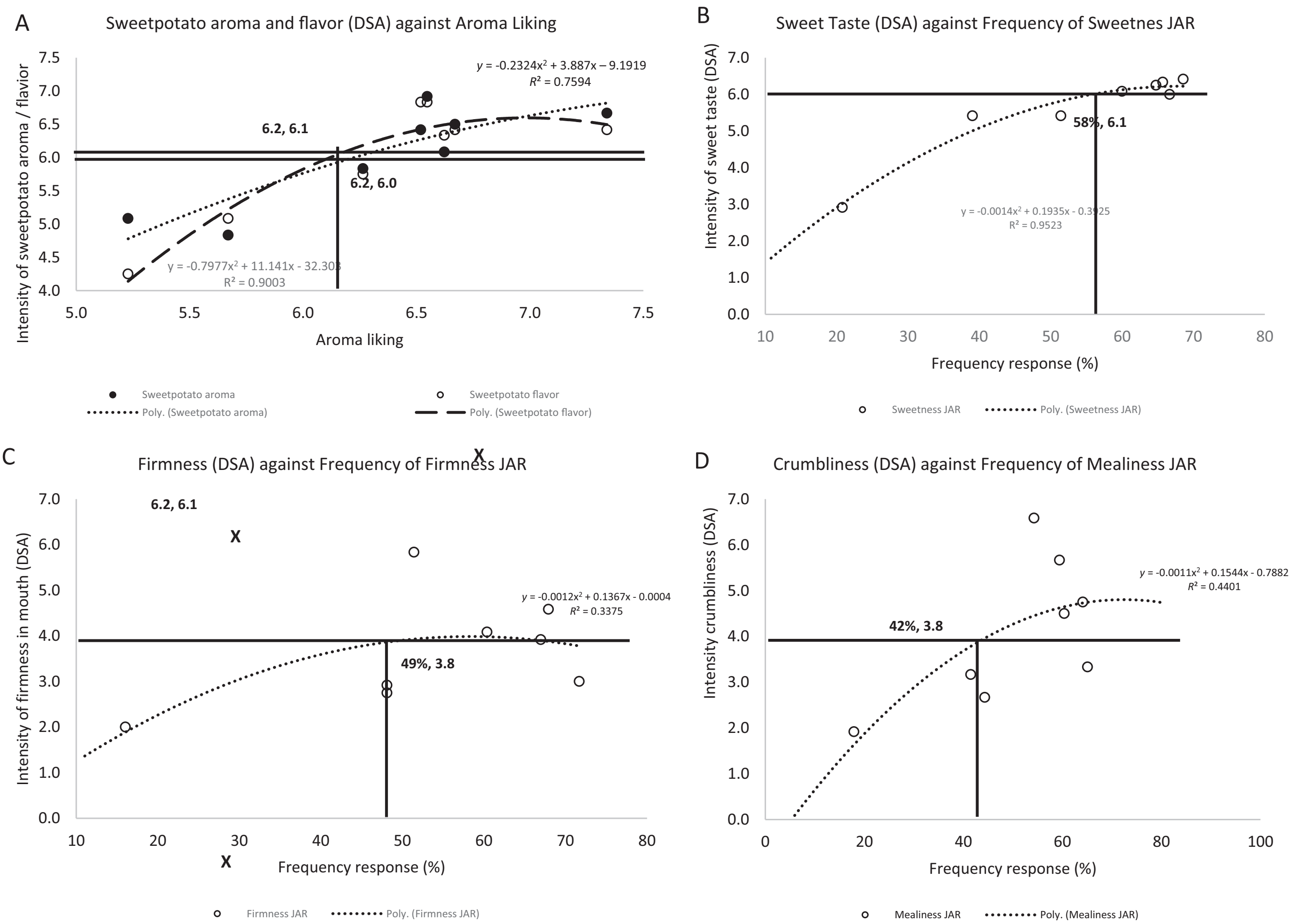

Figure 4. Plots showing relationships between consumer acceptability ratings and descriptive sensory attribute intensities [(A) sweetpotato aroma/flavor against aroma liking; (B) frequency response to Jar question on sweetness against sweet taste; (C) frequency response to JAR question on firmness against firmness in mouth; and (D) frequency response to JAR question on mealiness against crumbliness] and the proposed cut-off for each attribute denoted by intersection of vertical and horizontal lines marked on each plot.

to an overall liking of 6 (Fig. 3A). This aroma liking value was then used to determine the minimum sweetpotato aroma and flavor intensities that would be expected in a well-liked sweetpotato (Fig. 4). Similarly, overall liking was related to the distribution of responses for the JAR questions on sweet taste ($r^2 = 0.92$ for JAR), firmness ($r^2 = 0.62$ for JAR) and mealiness ($r^2 = 0.57$ for just about right) as shown in Fig. 3(B–D).

The proposed threshold values for each of the descriptive sensory attributes that were associated with these consumer acceptability measures is shown in Fig. 4. The proposed minimum average target scores were 6 (moderate) for sweetpotato aroma, sweetpotato flavor and sweet taste. The proposed minimum average target score for firmness was 4, which is perceived as 'firm'. Lastly, the proposed minimum target average mealiness score was 4 which is midway between 'slight' and 'moderate'.

Regression decision tree scoring system for screening sweetpotato varieties in breeding programs

Figure 5 shows the regression decision tree tool created to calculate a selection index for eating quality traits when screening clones in sweetpotato breeding programs. The decision tree was constructed based on the target scores established for the essential eating quality traits, which were related with overall liking (Fig. 4). As a result, a scoring system for calculating an overall eating quality score was created. Because only four priority characteristics were considered for this study, the maximum possible eating quality score is 4. Notably, sweetpotato aroma and flavor are both attributes related with consumer perception of a 'good smell', and so genotypes that meet the threshold for either one are expected to meet consumer requirements. As such, both attributes contribute to a score of 1.

When applied to the nine genotypes used in the present study, the scores range from 1 to 4 in Hoima and 0 to 4 in Kamuli. Only 'D20' had a perfect score in both districts (Table 4). 'NASPOT 8', a leading market variety in the orange fleshed pipeline, had a perfect score in Hoima but scored 2 in Kamuli. When applied to the archived data for 59 sweetpotato samples from the 2022A harvest, 52% of the genotypes had a perfect score (see Supporting information, Fig. S1). Many of the genotypes included were at the stage of advanced yield trials.

DISCUSSION

Gender responsiveness is achieved in a breeding program when gender implications of priorities are queried.[25] The application of the G+ product query in the present study facilitated the

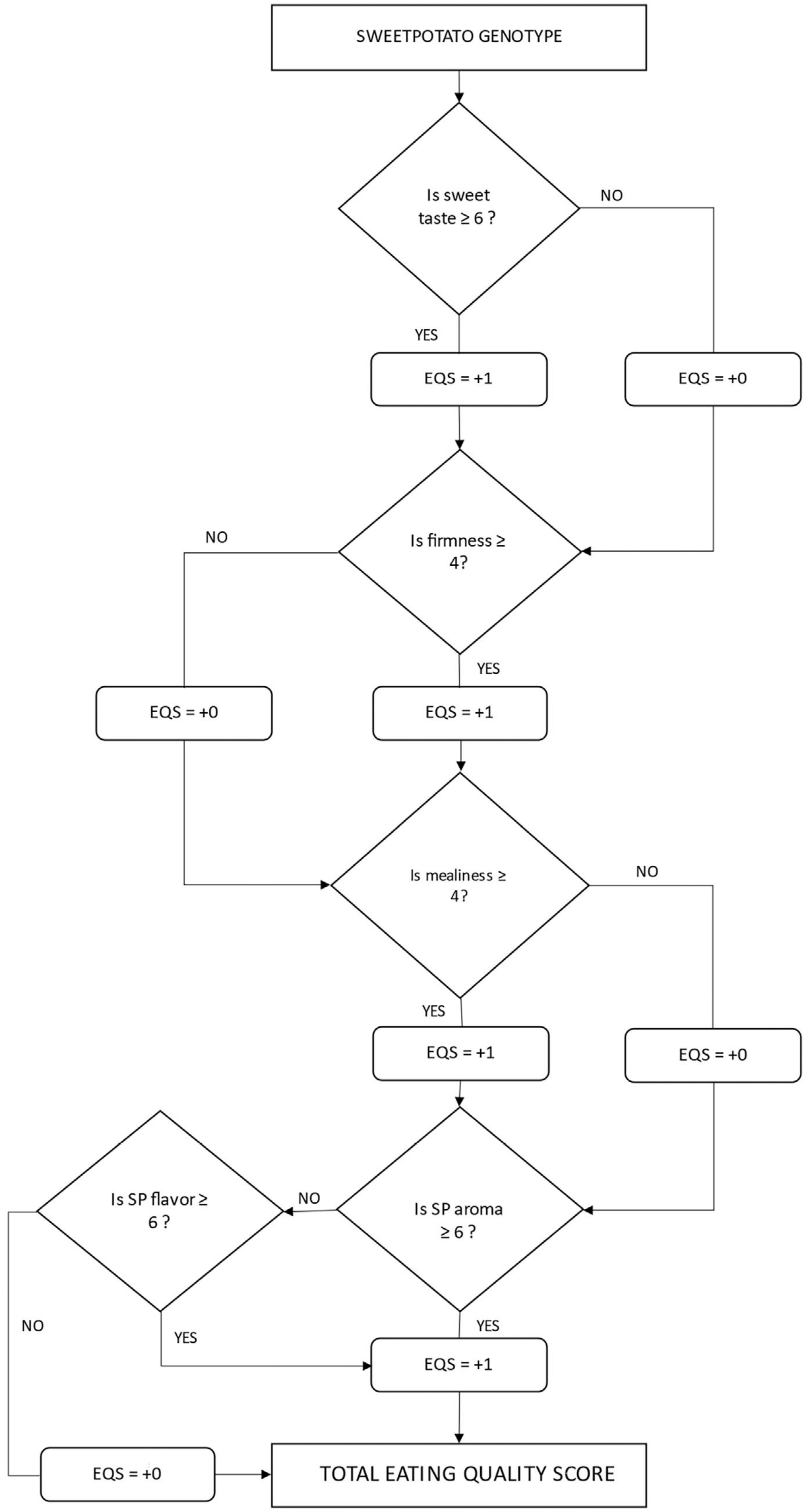

Figure 5. Decision tree to guide calculation of eating quality score (EQS) for integration into breeding selection index.

Table 4. Total eating quality index scores for the nine genotypes used in the present study

Genotype	Total eating quality score	
	Hoima	Kamuli
'D11'	2	2
'D20'	4	4
'Muwulu-Aduduma'	2	2
'NAROSPOT 1'	2	4
'NASPOT 8'	4	2
'NKB105'	1	1
'NKB3'	0	1
'Umbrella'	4	
'NKB135'		0

revision of the earlier defined product profile to ensure setting gender responsive breeding targets. All of the eating quality characteristics considered in the present study were gender neutral, and essential to have on the priority list reinforcing the value of breeding for these characteristics. In other words, they would not cause or promote gender biases. Hence, no adjustments were necessary to mitigate negative gender implications of their inclusion in the breeding program. This finding provides support for the claim that the resulting tool is gender responsive[25] because it augurs gender mainstreaming by acknowledging existing gender inequalities and thereafter identifying mitigation strategies. Such strategies then intentionally accompany design and release of new varieties to avert deepening gender disparities and hence increasing the likelihood of adoption. Omitting this step would pose a risk of releasing modern varieties that benefit one gender at the peril of another hence increasing gender disparities among target communities. For example, women in Uganda have a unique role to select and prepare food for household consumption, constitute a big proportion of sweetpotato farmers and retailers and own small-scale businesses including local restaurants and food shelters.[30] Breeding sweetpotato for sensory characteristics would ease food preparation, and enhance profit margins by increasing their market share.[30]

Generally, consumers in Kamuli showed a more positive response to the samples than those in Hoima as indicated by the higher consumer liking ratings and bigger proportion of respondents perceiving samples to have appropriate intensities of sweetness, firmness and mealiness. The proportion of consumers who perceived none of the sweetpotato genotypes to be excessive in sweetness, firmness or mealiness was small as illustrated by the JAR scale findings. One argument for this is that consumers were not sensitive to excessive intensities of these attributes. This may be the case for consumers in Hoima regarding mealiness and firmness. Here, only 14% and 9% of respondents perceived 'D11' (a particularly firm and mealy genotype) to be too firm and too mealy, respectively. Furthermore, a bigger proportion of consumers (34% and 37%) considered it to be less firm and mealy than they would prefer. However, this argument is limited to 'D11' in Hoima because the results from DSA indicated that the variation among the samples was small, with most of them having low to moderate firmness and mealiness intensities. As such, future studies should include varieties with a wider range of sweetness, firmness and mealiness intensity to confirm this observation.

There was variation in sensory characteristics by location which could indicate the influence of environmental conditions on phenotypic characteristics. However, this observation seems to be more apparent for two genotypes ('D20' and 'D11'). Although the intensity of several sensory characteristics of 'D11' concerning appearance, flavor and texture varied by location, only color distribution varied for 'D20'. Previous studies have demonstrated interactions between environment and nutritional characteristics of sweetpotatoes such as dry matter and beta-carotene contents.[33] This variation could have partly contributed to the different responses towards 'D11' among consumers in Hoima and Kamuli. Such regional variations in varietal characteristics also reflects why the premium price for the same product may vary by region. Therefore, breeders need to target different environments with different varieties.

Color liking was related to overall liking in contrast to findings by Moyo *et al.*[17] Although a previous study indicated that consumers preferred bright and uniform colors,[16] consumers in the present study liked a wide variety of hues and both heterogenous and uniformly distributed colors. It is also possible that consumer color preference is based on interactions between various aspects of color and not a singular color attribute.

The regression decision tree in the present study is a practical quality control tool that can be used by the breeders directly and otherwise. Even though classical DSA is challenged by high cost and low throughput, it is still the gold standard for generating sensory profiles[21] and should be used whenever practical. In sweetpotato breeding, the later stages when there are fewer genotypes being tested is one example of such instances as indicated by the samples in the advanced yield trial that were used to test the tool in the present study. However, the tool can also be integrated with high throughput methods of laboratory analysis such as image analysis.[34] This approach can serve as a quality control tool to facilitate gender responsive selection for consumer preference at earlier stages of breeding when 100 of genotypes are studied. The tool, however, does not include target values for alternative biophysical or biochemical measures that can be used for deducing sensory quality of sweetpotato such as instrumental texture analysis[23] and enzymatic activity for texture characteristics, sugar composition for sweet taste and volatile organic compounds for flavor characteristics.[35] This limits the application of this tool to programs that have DSA protocols integrated in routine product analysis. Future studies should build on the work started here by establishing and incorporating qualitative and quantitative thresholds for these additional measures to extend the application of this tool.

The study shows strong evidence for the quality of 'D20', an orange fleshed genotype. Being the only genotype that produced a perfect eating quality score, it outperformed the current leading market variety, 'NASPOT 8'. Furthermore, the variation in its appearance by region did not affect the positive response it received from consumers in both districts.

The eating quality score calculated from the decision tree is expected to provide a marketing strategy for the released varieties. Thiele *et al.*[12] highlighted the importance of including the promotional messages to market 'modern' varieties at release. The eating quality score can be easily communicated as a ratio of calculated score to perfect score (foue) to indicate to consumers the extent to which the genotype meets consumer needs. Additionally, the tool developed here also demonstrates a different way to facilitate multiple disciplines in breeding programs. Gender analysis was used to inform, in part, the direction of a food science tool to be used in an economic selection index developed by socio-economists, thus creating a linking across outputs and harmonious application of tools from multiple disciplines. In this way, the independent role but complementary that each discipline plays in breeding is emphasized and development of competing tools which could overwhelm breeders is avoided.

CONCLUSIONS

The present study assessed the gender implications of sensory characteristics in the sweetpotato product profile to ensure development of a gender responsive breeding selection criterion. To the best of our knowledge, this is the first time that this has been carried out for sweetpotato. It also relates results from consumer and descriptive sensory analysis to propose the threshold values for sweetpotato aroma and flavor, sweet taste, firmness, and mealiness based on consumer acceptability. These values were used to design a regression decision tree to guide breeders when drawing inferences about results from descriptive sensory analysis of sweetpotato samples. Such a tool that includes consumer needs and gender considerations will facilitate demand-led breeding and make varietal selection in sweetpotato breeding programs more effective.

AUTHOR CONTRIBUTIONS

MS, RTS and HdK were responsible for conceptualization. MS, SM and SET were responsible for data curation. MS, SM and SET were responsible for formal analysis. RTS, YB, TM and CB were responsible for funding acquisition. MS, RTS, MM, SM, YB, DC, FO, SET and CB were responsible for investigations. MS, RTS, MM, HdK, SDJ, IB, JJO, SM, YB, DC, FO, SET and CB were responsible for the methodology. RTS, TM and CB were responsible for project administration. RTS and YB were responsible for resources. RTS, MM, HdK, SDJ, SM, YB, TM and CB were responsible for supervision. MS and RTS were responsible for reviewing and editing: MS, RTS, MM, HdK, SDJ, IB, JJO, SM, YB, DC, FO, SET, TM and CB were responsible for writing the original draft.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ETHICAL STATEMENT

The research described in this manuscript (from laboratory through consumer preferences interviews and surveys) has been previously and formally approved by the competent authority(es) within each country [Makerere University School of Social Sciences Research Ethics Committee (MAKSSREC 12.19.364), Centre de Coop´eration Internationale en Recherche Agronomique pour le D´eveloppement (French Agricultural Research Centre for International Development), CIRAD, Ethics committee, and by the Faculty of Natural and Agricultural Sciences, University of Pretoria (NAS 236/2021)]. Written informed consent was obtained for all study participants and is available'.

DATA AVAILABILITY STATEMENT

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

SUPPORTING INFORMATION

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

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