Research Article

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East African highland cooking banana: towards an efficient selection of hybrids with user-preferred food quality traits

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Abstract

BACKGROUND: Determinants of culinary qualities of East African highland cooking bananas (EAHCB) are not well known. This constrains the inclusion of user-preferred traits in breeding. The present study aimed to quantify key indicators of user-preferred characteristics to enable selection of acceptable hybrids.

RESULTS: Qualitative characteristics that drive preference were big bunches (15–34 kg), long straight/slightly curved fingers (12–23 cm), yellowness and soft texture. Descriptive sensory analysis of the intensity of colour and texture the 23 genotypes revealed that landraces Kibuzi, Mbwazirume, Nakitembe and Mpologoma had higher intensity of yellowness and lower intensity of hardness (softer) and a low score (≤ 1.0) of astringency taste. A preference test showed that they had higher acceptability scores. Biochemical, instrumental and sensory data revealed correlations between sensory firmness and instrumental hardness ($r = 0.5$), sensory firmness and amylopectin ($r = -0.54$), suggesting that qualitative descriptions can be predicted by instrumental and biochemical indicators. Significant ($P < 0.05$) variations in amylose and total starch content were observed in different varieties. Moderate correlations between instrumental hardness and firmness in mouth ($r = 0.55$), cohesiveness and firmness in the mouth ($r = 0.57$), and adhesiveness and firmness in the mouth ($r = 0.64$) were observed. Surprisingly, carotenoids content was not correlated with yellowness in cooked matooke. However, positive correlations were observed between chroma (b^*) parameters of raw matooke and sensorial assessed color on cooked samples.

CONCLUSION: Qualitative characteristis; the bunch, pulp colour and texture; that drive users-preference in the EAHCB were quantified, paving way for breeders to use them to select genotypes with these attributes early in the breeding process.

Keywords: matooke; effective breeding; consumer preference; high-throughput phenotyping; varietal adoption

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INTRODUCTION

Farming communities in the Great Lakes Region of East Africa rank the East African Highland Cooking Bananas (EAHCB) as their most important crop.[1-4] The crop's year-round fruiting habit[5] guarantees continuous availability of food and income to the farm families. Recently, producing EAHCB is becoming increasingly difficult because of pests, diseases and limited germplasm diversity, among other constraints. Landrace cultivars are generally susceptible to pests and diseases.[6-9]

The deployment of host plant resistance to reverse the effects of these constraints is considered to be the most effective option for low-resource rural households.[3] As a result, the improvement of the susceptible landraces through breeding is a priority strategy.[10,11] However, breeding of EAHCB is constrained by lack of tools and knowledge to properly select hybrids that combine resilient productivity with culinary qualities and preferences based on local tastes and traditions.

EAHCBs are harvested, peeled and cooked for a meal at mature but green stage.[12] When cooked, the fruit is characterized by a unique insipid taste and aroma, golden yellow color and a tender texture. These attributes have endeared an EAHCB meal to consumers and constitute the unique quality described as *tookeness*[13,14] originating from the term *matooke*, used to describe a cooked meal of EAHCB. Consumers look for these attributes and therefore improved hybrids must possess them to be adopted. Most of the banana hybrids developed so far have been rated by consumers as inferior to local cultivars with respect to almost all sensory attributes, implying that they lack the required *tookeness* qualities. Unfortunately, these qualities are poorly defined, making it difficult to efficiently breed and select user-acceptable hybrids. EAHCB breeding is a lengthy process involving the generation of a large number of genotypes, which are then evaluated using sensory techniques. However, user feedback comes late in the breeding scheme and thus cannot be incorporated into early-stage selection efforts.[15] It is therefore imperative to translate the qualitative descriptions of preferred characteristics into objective instrumental and biochemical indicators that are deployable sufficiently early in the breeding process.[16]

The present study aimed to build on previous research[4,17,18] that identified user preferred quality characteristics by quantifying selected qualitative indicators of the user-preferred qualities of EAHCB into quantitative metrics to enable their utilization in early and efficient selection of hybrids tailored to user needs.

MATERIALS AND METHODS

Twenty three EAHCB diverse landraces (Mpologoma, Enzirabahima, Musakala, Mbwazirume, Nakitembe, Kibuzi, Kisansa, Nandigobe, Nakinyika and Nfuuka) and improved hybrids (NARITA2, NARITA 4, NARITA6, NARITA8, NARITA11, NARITA12, NARITA14, NARITA15, NARITA 17, NARITA18, NARITA19, NARITA 21 and NARITA23) were selected and used in the instrumental, sensory and biochemical assessments of their quality descriptors.

Previous studies identified the user-preferred physical and sensory quality characteristics of EAHCB and their descriptors.[4,17,18] In the present study, the bunch, finger, colour and textural qualitative user-preferred characteristics were translated into quantitative metric measurements to aid high-throughput screening of a large number of genotypes.

Six focus group sessions comprising of 12 farmers, 12 processors and 12 traders, men and women categorised 30 bunches into three groups: *big*, *medium* and *small*. Five bunches were randomly picked from the three categories for the measurements. The bunches were individually weighed using a weighing scale and means computed. Compactness was assessed by randomly picking five bunches from three categories of bunches, described by farmers, processors and traders as: *too compact*, *medium* or *loose*. Level of compactness was estimated by measuring the gap between clusters and fingertips with a measuring tape on five fingers. The finger lengths were quantified by measuring the distance from tip to tip at the distal end, whereas the girth was measured at the widest point of five fingers taken from second and third clusters on five randomly selected bunches. Finger curvature was estimated by the ratio of the inner to outer curve of the fingers.[19]

The textural, colour and astringency taste attributes were determined by cooking as described by Nowakunda *et al.*[12] The cooked samples were subjected to a 12-member descriptive sensory panel using a 10-point intensity scale for each attribute as described in the matooke lexicon by Khakasa *et al.*[17] The published matooke sensory lexicon was used in the sensory assessment of quality traits.[12] The acceptability of the same genotypes was evaluated by a 30-member panel of matooke consumers using a nine-point hedonic scale.[20]

For the instrumental and biochemical assessments, five bunches from plants of each genotype were harvested at the full green maturity stage[21] for the assessments from on-station banana breeding experimental fields at the National Agricultural Research Laboratories Institute and Sendusu-International Institute of Tropical Agriculture-Uganda station in central Uganda.

Measurements of all the parameters were taken on clusters selected from the second, third and fourth hands of the bunches in three replicates per measurement. The instrumental textural properties of the raw and cooked sample hardness, cohesiveness and adhesiveness were determined using a texturometer (TMS-Pilot),[12] whereas color was determined with a Minolta chromameter (CR-400) (Konica, Tokyo, Japan).[22] The biochemical indicators prioritized for textural properties were total starch and amylose/amylopectin, and were determined using the colorimetric method.[23] Carotenoids and polyphenols were used as indicators of the yellow color in matooke. Carotenoids were determined by methods described by Englbeger *et al.*[24] and the polyphenols by the Folin–Ciocalteu method as described by Bashmil *et al.*[25]

The instrumental, biochemical and sensory data were analyzed using XLSTAT 2019.3.2 (Addinsoft, Paris, France) through linear regressions, correlations and principal component analysis (PCA) to examine relationships and potential to predict the sensory indicators using instrumental or biochemical indicators of texture and yellow color. Analysis of variance and a post-hoc Duncan's test were conducted to assess variation among genotypes.

RESULTS

Bunch and fruit characteristics

The fruit and finger characteristics were quantified and their acceptability ranges were established (Table 1). Matooke users considered a bunch that weighed 34 kg and above as *big*, whereas bunches below 15 kg were considered *small*. Bunches that weighed 15–34 kg were desirable. Similarly, fingers for which the length was ≥ 23 cm were considered long and those that were ≤ 12 cm were considered short. Thresholds for finger curvature, represented by a ratio between the outer and inner curvature, was 0.65–1.00 (Table 1). In addition to gender implications, bunches with weights

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Table 1. User-desirable thresholds for bunch and fruit characteristics

Characteristic	Description	Desirable range	Remarks	
Bunch size	Weight (kg) Weighed with peduncle cut at the first scar	15–34	Below 15 kg is not desired Above 34 kg may be uneconomical because pricing matooke is not by weight. It could also be too heavy for women.	
	Circumference (cm)	78–114	Girth measures around the second and third cluster	
	Number of clusters	7–12		
	Compactness (cm)	1 = 4.3 2 = 3.0	1 = Distance between fingertips 2 = Distance between clusters	
Finger size	Length (cm)	12–23	Tip to tip on distal side	
	Circumference (cm)	10–14		
	Curvature	0.65–1.0	Ratio of inner to outer finger curvature	

> 34 kg have no economic advantage over those that are below because pricing of matooke on the market is not based on weight but on visually assessed size. Also, women in the Focus Group discussions found that too long or large fingers are difficult to handle when peeling.

Descriptive sensory analysis of textural, colour and astringency taste

The results of descriptive analysis are presented in Table 2. The colour of all the landrace genotypes were scored 7.4 and above, suggesting that the preference for intensity of yellowness in the matooke was high (towards a maximum of 10).[17] These descriptive scores coincided with genotypes with highly acceptable quality characteristics.[4,18]

Landraces Kibuzi, Mbwazirume, Nakitembe and Mpologoma, all of them highly liked by users, were < 3.0, suggesting that users favor a soft texture (Table 2). Hybrids NARITA19 and NARITA 21, also scored below 3.0 for texture. On the other hand, the texture of hybrids NARITA 6, NARITA 15 and NARITA 2 were > 7.0, indicating that they were unacceptably hard. Most of the other hybrids were scored between 2.5 and 5.0, indicating that they had firm textures (Table 2).

For astringency taste, all the landraces were scored ≤ 1.0 suggesting a preference for low astringency. Although most of the hybrids also had astringency levels ≤ 1.0, NARITA 14, NARITA 17, NARITA 21, NARITA 24, NARITA 19 and NARITA 11 scored ≥ 1.5 (Table 2).

The acceptability rating of the 23 genotypes by matooke consumer on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) showed that all the landrace genotypes were between 7.0 and 9.0, a range that implies liking to extreme liking (Table 2). With the exception of NARITA 4 and 17, all other NARITAs (hybrids) were scored at 6.0 or below, implying that their acceptability ranged between slight liking to extreme dislike of the genotypes.

Fruit pulp texture

The instrumentally assessed indicators of textural properties were hardness on raw samples and hardness, cohesiveness and adhesiveness on cooked samples (Table 3). The results show significant differences between hybrids and landraces. Hardness, among the instrumental parameters, was the most discriminating attribute for cooked matooke ($P < 0.002$). Hardness of landraces ranged from 2.06 and 4.75 and scores for the improved hybrids largely overlapped, except for NARITA 15 and NARITA 6, which had values > 5.74 (Table 3).

Fruit pulp colour

The L^* coordinate, which represents *lightness*, and b^*, which represents *yellowness*, were found to be the most useful coordinates in matooke. The a^* coordinates, which represent *redness*, was not relevant for matooke. The results show significant variations

Table 2. Bunch weight and descriptive sensory scores for colour, texture, and astringency taste

Genotype	Preference (1–9 hedonic scale)	Bunch weight (kg)	Colour (scale 0–10 intensity scale)	Texture (touch) (scale 0–10 intensity scale)	Astringency taste (scale 0–10 intensity scale)
Mbwazirume	9.02 a	20.9 ± 1.35	9.00 ± 0.56	2.89 ± 0.73	0.44 ± 0.86
Kibuzi	8.21 a	20.8 ± 1.81	8.75 ± 1.74	1.50 ± 1.01	0.57 ± 0.42
Enzirabahima	8.02 a	13.0 ± 0.00	8.57 ± 1.51	2.71 ± 0.11	1.00 ± 1.52
Nandigobe	7.12 b	17.2 ± 0.28	8.54 ± 0.33	2.08 ± 0.60	0.11 ± 0.61
Kisansa	8.21 a	25.8 ± 1.07	8.11 ± 2.22	3.00 ± 1.01	0.11 ± 0.68
Nakitembe	9.01 a	24.0 ± 2.05	8.00 ± 0.37	1.86 ± 0.37	0.14 ± 0.66
Mpologoma	8.21 a	26.8 ± 0.35	7.91 ± 1.70	1.27 ± 0.19	0.64 ± 0.61
Nfuuka	7.12 b	27.8 ± 1.81	7.89 ± 2.14	3.78 ± 0.34	0.33 ± 0.46
Musakala	8.23 a	25.1 ± 0.8	7.69 ± 1.43	2.08 ± 0.21	0.73 ± 0.71
Nakinyika	7.30 b	14.7 ± 0.99	7.45 ± 0.97	4.22 ± 0.46	0.80 ± 0.88
NARITA17	7.01 b	34.5 ± 4.09	6.70 ± 1.98	3.78 ± 0.64	1.56 ± 0.72
NARITA14	6.03 b	22.7 ± 1.01	6.22 ± 1.2	5.57 ± 1.16	1.50 ± 0.38
NARITA2	6.12 b	26.4 ± 0.42	5.75 ± 1.33	7.71 ± 3.07	1 0.00 ± 0.97
NARITA6	3.21 d	26.3 ± 0.28	5.50 ± 1.41	8.00 ± 3.80	0.29 ± 0.59
NARITA15	3.51 d	38.0 ± 4.27	5.44 ± 2.10	7.27 ± 2.45	0.73 ± 0.69
NARITA12	3.02 d	25.0 ± 3.02	5.38 ± 1.49	4.75 ± 1.62	0.67 ± 0.59
NARITA4	8.02 a	26.4 ± 3.28	5.14 ± 1.40	5.00 ± 1.17	1.00 ± 0.35
NARITA11	5.14 c	16.5 ± 0.68	5.07 ± 0.67	5.57 ± 1.13	2.75 ± 1.02
NARITA18	3.31 d	29.5 ± 2.73	4.56 ± 1.30	4.27 ± 0.86	0.55 ± 0.29
NARITA23	2.51 d	29.0 ± 0.81	2.23 ± 0.96	4.27 ± 0.99	0.55 ± 0.56
NARITA19	6.02 c	35.7 ± 2.19	2.00 ± 0.08	2.38 ± 1.98	2.25 ± 1.29
NARITA8	2.23 d	29.8 ± 2.14	1.63 ± 2.18	3.38 ± 1.49	0.86 ± 0.44
NARITA21	2.21 d	31.2 ± 1.55	1.30 ± 2.61	2.70 ± 1.42	1.80 ± 0.24

Top: 10 landraces. Bottom: 13 improved hybrids. Genotypes within each group have been ranked based on the colour score.
Values are the mean ± SD. Values with same letters are not significantly different.

Table 3. Instrumental textural and color (hunters) properties of cooked EAHCB genotypes

Genotype	Hardness (N)	Cohesiveness	Adhesiveness (N)	*L**	*b**
Musakala	2.06 fghi	0.59 a	0.50 a	60.50 abcd	28.60 bcd
Nfuuka	2.32 efghi	0.52 a	−0.54 bcd	41.30 h	33.00 a
Kibuzi	2.340 efghi	0.50 a	−0.52 bcd	62.10 ab	27.80 bcde
Mbwazirume	3.01 defghi	0.73 a	−1.72 de	42.90 fgh	29.10 bcd
Nandigobe	3.66 cdefghi	0.74 a	−0.70 bcd	60.90 abc	28.70 bcd
Kisansa	3.69 cdefghi	0.73 a	0.37 b	52.79 bcdef	26.60 de
Nakitembe	4.03 cdefgh	0.51 a	−0.45 bcd	62.10 ab	27.80 bcde
Mpologoma	4.110 cdefg	0.740 a	−0.480 bcd	60.700 abcd	28.900 bcd
Nakinyika	4.680 cde	0.810 a	−1.070 cd	43.700 fgh	27.300 cde
Enzirabahima	4.75 cde	0.53 a	−0.79 bcd	60.40 abcd	28.40 bcd
NARITA21	1.34 i	0.87 a	−1.26 cd	54.30 abcde	26.90 de
NARITA11	1.72 ghi	0.46 a	−0.36 bcd	59.97 abcd	28.80 bcd
NARITA17	3.01 defghi	0.48 a	−0.47 bcd	52.90 bcdef	30.00 b
NARITA 4	3.33 cdefghi	0.59 a	−0.52 bcd	63.70 a	28.80 bcd
NARITA14	3.50 cdefghi	0.511 a	−0.91 bcd	54.65 abcde	28.51 bcd
NARITA8	3.72 cdefghi	0.56 a	−0.66 bcd	58.405 abcd	27.94 bcd
NARITA23	4.01 cdefgh	0.51 a	−0.72 bcd	42.30 gh	25.30 ef
NARITA12	3.87 cdefghi	0.844 a	−0.83 bcd	44.39 efgh	24.02 f
NARITA2	4.43 cdef	0.55 a	−0.37 cd	58.82 abcd	29.705 bc
NARITA19	4.45 cdef	0.79 a	−0.68 bcd	51.09 cdefgh	27.02 de
NARITA18	5.08 cd	0.49 a	−0.79 bcd	50.40 defgh	27.85 bcde
NARITA15	7.64 ab	0.51 a	−0.41 bcd	59.53 abcd	28.23 bcd
NARITA6	8.66 a	0.518 a	−0.65 bcd	61.83 ab	28.80 bcd

Top: 10 landraces. Bottom: 13 improved hybrids. Genotypes within each group have been ranked based on the colour score.
Values with same letters in the same column are not significantly different ($P < 0.05$).

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among the raw samples (Table 3). The measurements were taken on raw samples to be able to establish correlation between them and sensory parameters of cooked samples. *L** values in landraces ranged from 41.3 to 62.1 and a similar range of values was observed for the hybrids (41.3–63.7). Similarly, *b** ranged between 27.3 and 33.0 in the landraces, and most hybrids showed similar results with few exceptions (NARITA 8 and NARITA 23 had scores < 25.5). Hunter values therefore could not distinguish clearly between landraces and improved hybrids.

The results of the Pearson's correlation analysis (Table 4) showed that sensory firmness, moistness, smoothness, hardness, mouldability and stickiness were correlated with instrumentally assessed hardness and cohesiveness. Firmness in the mouth ($r = 0.50$) and hardness by touch ($r = 0.51$) were moderately correlated with instrumental hardness. These results further showed that sensory textural properties were negatively correlated with biochemical properties. There was a weak and negative correlation between firmness in the mouth and amylopectin ($r = -0.54$), total starch ($r = -0.49$) and with amylose content ($r = -0.33$). Likewise, hardness by touch was also negatively correlated with biochemical properties; amylopectin ($r = -0.46$), total starch ($r = -0.41$) and amylose ($r = -0.35$).

Table 4. Pearson (*n*) correlation matrix for sensory, instrumental and biochemical attributes

Variables	Firmness M	Moisture M	Smoothness M	Hardness T	Moldability T	Stickiness T	Hardness (N)	Cohesiveness	Adhesiveness	Amylose	Amylopectin	Total starch
Firmness M	**1**	−0.399	**−0.607**	**0.972**	**−0.617**	−0.392	**0.500**	**0.565**	**0.643**	−0.331	**−0.536**	**−0.487**
Moisture M		**1**	**0.658**	**−0.431**	**0.627**	**0.804**	−0.090	0.401	0.308	−0.080	**−0.419**	−0.348
Smoothness M			**1**	**−0.699**	**0.926**	**0.626**	−0.196	0.142	0.020	−0.077	−0.128	−0.226
Hardness T				**1**	**−0.699**	**−0.424**	**0.512**	**0.497**	**0.585**	−0.354	**−0.458**	**−0.406**
Moldability T					**1**	**0.588**	−0.160	0.140	0.025	−0.124	−0.123	−0.191
Stickiness T						**1**	−0.191	0.425	0.350	−0.052	**−0.455**	−0.344
Hardness (N)							**1**	0.359	0.338	−0.335	−0.343	−0.233
Cohesiveness								**1**	0.984	−0.559	**−0.971**	**−0.902**
Adhesiveness									**1**	−0.550	**−0.958**	**−0.864**
Amylose										**1**	0.380	**0.516**
Amylopectin											**1**	**0.875**
Total starch												**1**

Values in bold are different from 0 with a significance level of alpha = 0.05. M, tested in the mouth; T, tested by touch.

Biochemical components

The total starch and amylose contents, measured in the 23 genotypes, are presented in Table 5. The genotypes have significantly different total starch and amylose contents. Amylose content

Table 5. Total starch and amylose content in fruits from selected EAHCB genotypes

Genotypes	Amylose (g kg^{-1})	Total starch (g kg^{-1})
Nakinyika	138.0 jk	869.0 a
Nandigobe	138.6 jk	682.5 c
Nfuuka	156.2 hij	568.0 f
Nakitembe	177.0 gh	752.0 b
Musakala	220.0 cde	613.0 e
Mbwazirume	226.0 cd	499.0 g
Kibuzi	226.0 cd	765.0 b
Kisansa	238.0 bcd	568.0 f
Enzirabahima	248.0 c	778.5 b
Mpologoma	323.5 a	692.0 c
NARITA 2	126.0 k	673.0 c
NARITA 18	126.0 k	678.0 c
NARITA 17	144.0 ijk	657.0 cd
NARITA 23	145.0 ijk	769.0 b
NARITA 4	169.0 ghi	757.0 b
NARITA 21	188.0 fg	659.0 cd
NARITA 19	195.5 efg	881.5 a
NARITA 12	212.0 def	776.0 b
NARITA 14	226.0 cd	746.0 b
NARITA 11	229.0 bcd	675.0 c
NARITA 8	238.5 bcd	792.0 b
NARITA 15	239.0 bcd	749.0 b
NARITA 6	257.5 b	773.0 b
Pr > *F* (model)	< 0.0001	0.027

Top: 10 landraces. Bottom: 13 improved hybrids. Genotypes within each group have been ranked based on the amylose content. Values with the same letters in the same colomn are not significantly different.

among landraces ranged from 138.0 to 323.5 g kg^{-1}, whereas, for the hybrids, the range was 126.0–257.5 g kg^{-1}. Although the ranges overlapped considerably, the average for landraces (209.13 g kg^{-1}) was higher than that for hybrids (191.96 g kg^{-1}). Similarly, the range for total starch content was 499.0–869.0 (average 678.70 g kg^{-1}) for landraces and 657.0–881.5 for the hybrids (average 737.40 g kg^{-1}). Generally, the landrace matooke genotypes known for user-preferred soft texture[26] have the lowest amylose content, with exception of NARITA 2, and NARITA 18, which had very low levels on amylose content (Table 2). Of these, NARITA 2 showed a fair preference, whereas NARITA 18 had limited acceptance (Table 2).

The hypothesized biochemical contributors to color were carotenoids, tannins and polyphenols. Although results showed significant differences among 23 genotypes, there was no clear contrast between landraces and hybrids (Table 6). The landrace genotypes ranged between 0.03 and 0.05 g kg^{-1}. The averages for polyphenols were 0.041 g kg^{-1} (range 0.030–0.051) and 0.040 g kg^{-1} (range 0.033–0.057) for landraces and hybrids, respectively. Hybrid NARITA 6 was an outlier with a total polyphenol content of 0.057 g kg^{-1}. The average carotenoids content was the same for landraces and hybrids (0.006 g kg^{-1}) and the ranges of values for each group were very similar. NARITA 12, one of the hybrids that was not liked by users (Table 2), had the highest carotenoid content (0.0093 g kg^{-1}). Mbazirume and Nakitembe, the most liked landrace cultivars, had carotenoid contents of 0.006 g kg^{-1} and 0.0051 g kg^{-1}, respectively. On the other hand, the tannins average for hybrids was 0.104 g kg^{-1} (range 0.049–0.187), which is slightly higher than the average of 0.094 g kg^{-1} (range 0.026 to 0.171) observed in landraces (Table 6).

Table 6. Hypothesized biochemical indicators for yellow matooke (raw) color from selected EAHCB genotypes

Genotypes	Phenolics (g kg^{-1})	Tannins (g kg^{-1})	Carotenoids (g kg^{-1})
Enzirabahima	0.030 i	0.059 ghijk	0.009 b
Mpologoma	0.036 efgh	0.137 abcde	0.006 gh
Nandigobe	0.036 efgh	0.036 k	0.004 k
Musakala	0.038 ef	0.157 abc	0.004 k
Nakinyika	0.039 ef	0.125 bcdef	0.008 c
Nakitembe	0.042 d	0.171 ab	0.005 j
Mbwazirume	0.046 c	0.106 cdefgh	0.006 g
Nfuuka	0.046 c	0.026 k	0.009 b
Kibuzi	0.047 c	0.0575 ijk	0.004 l
Kisansa	0.051 b	0.068 ghijk	0.007 e
NARITA 14	0.033 h	0.049 jk	0.008 b
NARITA 18	0.034 h	0.146 abcd	0.006 hi
NARITA 8	0.035 fgh	0.093 efghij	0.007 e
NARITA 2	0.035 gh	0.066 ghijk	0.006 f
NARITA 4	0.035 gh	0.127 bcdef	0.007 e
NARITA 15	0.036 efgh	0.089 efghij	0.007 d
NARITA 17	0.036 efgh	0.136 abcde	0.006 f
NARITA 12	0.037 efg	0.148 abcd	0.009 a
NARITA 21	0.038 ef	0.132 bcde	0.005 k
NARITA 11	0.046 c	0.078 fghijk	0.005 k
NARITA 19	0.046 c	0.187 a	0.003 m
NARITA 23	0.057 a	0.05 1ijk	0.006 i
NARITA 6	0.057 a	0.109 cdefg	0.008 cd

Top: 10 landraces. Bottom: 13 hybrids. Genotypes within each group were ordered by the phenolics contents.
Values with same letters in the same column are not significantly different ($P > 0.05$).

Relationships among instrumental, biochemical and sensory indicators

The PCA of instrumental, biochemical and sensory indicators for texture explained 79.1% of total variation (Fig. 1). Principal component (PC1) explained 43.6%, whereas PC2 explained 35.6% of the PCA. Twenty three genotypes were used for this assessment.

There were negative correlations between the biochemical indicators of texture (total starch and amylopectin) and instrumental hardness (texture). Amylose and amylopectin were not correlated with cohesiveness and adhesivenes, whereas moderate positive correlations were observed between instrumental hardness and sensory textural properties (firmness by mouth and hardness by touch (Fig. 1). Smoothness by mouth, moldability by touch, moistness in the mouth and stickiness by touch were explained by PC2, whereas cohesiveness, adhesiveness, firmness by mouth and hardness by touch were explained by PC1.

Landraces correlated highly with sensory textural attributes of smoothness in the mouth, moldability by touch, moistness in the mouth and stickiness by touch, as shown in first quadrant (Fig. 1). The hybrids NARITA2, NARITA6 and NARITA15 were correlated with instrumental hardness, total starch and amylopectin. The hybrids correlated with total starch and amylopectin are N4, N14, N17, N18, N19, N23 and NFK (Fig. 1).

The PCA explained 60.6% of variability of the relationships between instrumental, sensory and biochemical indicators of color (Fig. 2). PC1 showed 38.9% of variability and was explained by chroma parameter *b**, which depicts instrumental yellowness, yellow color and homogeneity of the color (sensory color attributes), together with total polyphenol content. Total carotenoids were moderately correlated with the chroma attribute *b**. There were no correlations between total carotenoids and the yellow color of the cooked matooke. However, the total polyphenols showed negative correlations with the yellowness in matooke. Instrumental color parameter *L** is not related to sensory color (Fig. 2).

DISCUSSION

Matooke users (farmers, traders, and consumers) prefer genotypes with big compact bunches, and with big, long and straight or slightly curved fingers. However, Marimo *et al.*[27] and Forysthe *et al.*[28] showed that very long or very big fingers are difficult to handle when peeling and straight fingers are difficult to pack in boxes for export markets. These characteristics are the first visual impressions that influence users' choice of EAHCB genotypes, similarly reported by Tumuhimbise *et al.*[26] and Madalla.[29] In addition, the genotypes should have a soft texture and yellow color when cooked. To be able to select improved hybrids that combine the above-mentioned characteristics, banana breeders generate thousands of new genotypes. The genotypes are then grown in different environments and across seasons for evaluation to select those that users would appreciate. Thus, the breeder gets feedback only at the end of the evaluation process and often with most of the hybrids having been rejected by the users, making breeding lengthy and costly.

In the present study, building on the work by Akankwasa *et al.*[4] and Marimo *et al.*,[18] we have suggested an approach that involves

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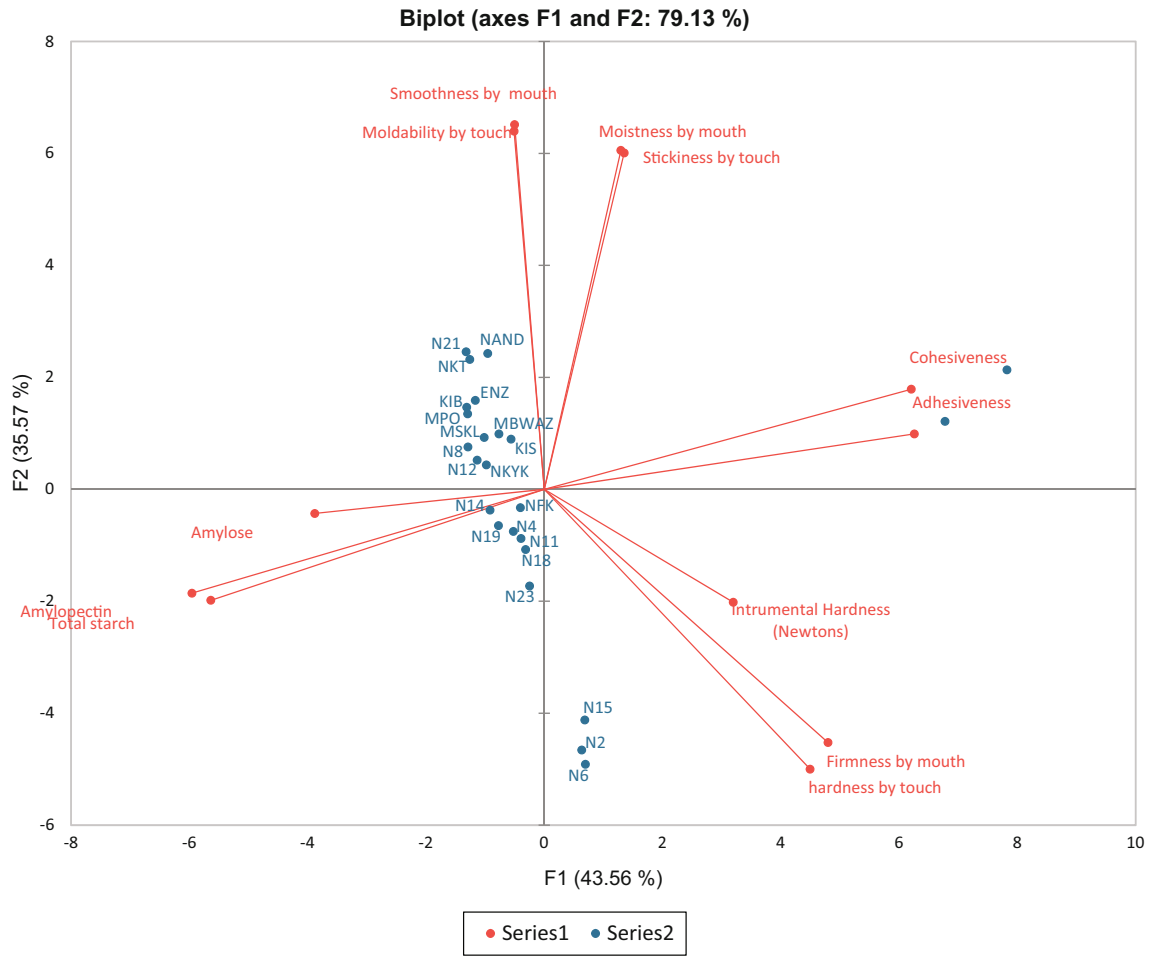

Figure 1. Biplot showing the relationship of genotypes with biochemical, instrumental and sensory parameters measured in selected EAHCB genotypes. N, NARITA; NFK, Nfuka; KBZ, Kibuzi; NYK, Nakinyika; MPO, Mpologoma; ENZ, Enzirabahima; KIS, Kisansa; KAB, Kabucuragye; MBZ, Mbwazirume; MVB, Muvubo; MSKL, Musakala.

identification, characterization and quantification of the indicators of the preferred characteristics, paving the way to the development of precise and faster screening tools.

Marimo *et al.*[27] and Nowakunda *et al.*[14] reported drudgery implications for women who harvest, lift and peel the bananas before cooking. Genotypes with big bunches and long fingers were desirable according to these earlier reports., In the present study, the bunch and finger characteristics were actually quantified into metric units (kg and cm) to better define bunch and finger sizes and characteristics. Breeders should select compact bunches that weigh 15–34 kg with straight or slightly curved fingers that are 12–23 cm in length (Table 1).

The descriptive sensory analysis panel showed that the landrace genotypes had the most intense yellow color, softer texture and a low intensity of astringency taste. Nowakunda *et al.*[30] and Nowakunda *et al.*[31] reported that matooke genotypes with high tannin content are often rejected by consumers. A preference taste showed that the landrace genotypes Mbwazirume, Nakitembe, Musakala, Mpologoma and Kibuzi were the most preferred (Table 2). In the studies by Marimo *et al.*[18] and Akankwasa *et al.*,[4] matooke users ranked the same genotypes among the most preferred cultivars. Hybrids NARITA 4 and NARITA 17 were scored closer to the most liked geneyopes, suggesting that they have a potential for adoption.

PCA analysis revealed that hardness, measured by penetration using a texturometer on cooked matooke, is predictive of sensory indicators such as firmness, smoothness in the mouth, moldability in the hand and moistness in the mouth (Fig. 1). This points to the possibility of predicting, in the laboratory, consumer reaction to this textural characteristic in genotypes during improved hybrid development, as well as selecting genotypes with user-acceptable level of hardness (between 2.0 and 5.0 N). Studies by Nowakunda *et al.*[30] and Marimo *et al.*[32] show that '*less hard*' or soft-cooked pulp is desirable by matooke consumers as validated by Fig. 1. Selection of improved hybrids based on texture was reported by Conner[33] in grapes and by Giongo *et al.*[34] in blueberries.

For biochemical indicators of textural properties, amylose was the most important (Table 4) Amylose is the less branched and well-packed component of starch, responsible for hard textural properties of starchy foods.[35] Most acceptable genotypes have amylose contents ranging between 130 and 325 g kg^{-1}). A PCA of color parameters measured with a color meter (instrumental) on raw matooke samples and the sensorial assessed color on cooked samples showed that they were positively correlated (Fig. 2).

It is expected that matooke genotypes with high carotenoid content would develop an intense yellow color when cooked

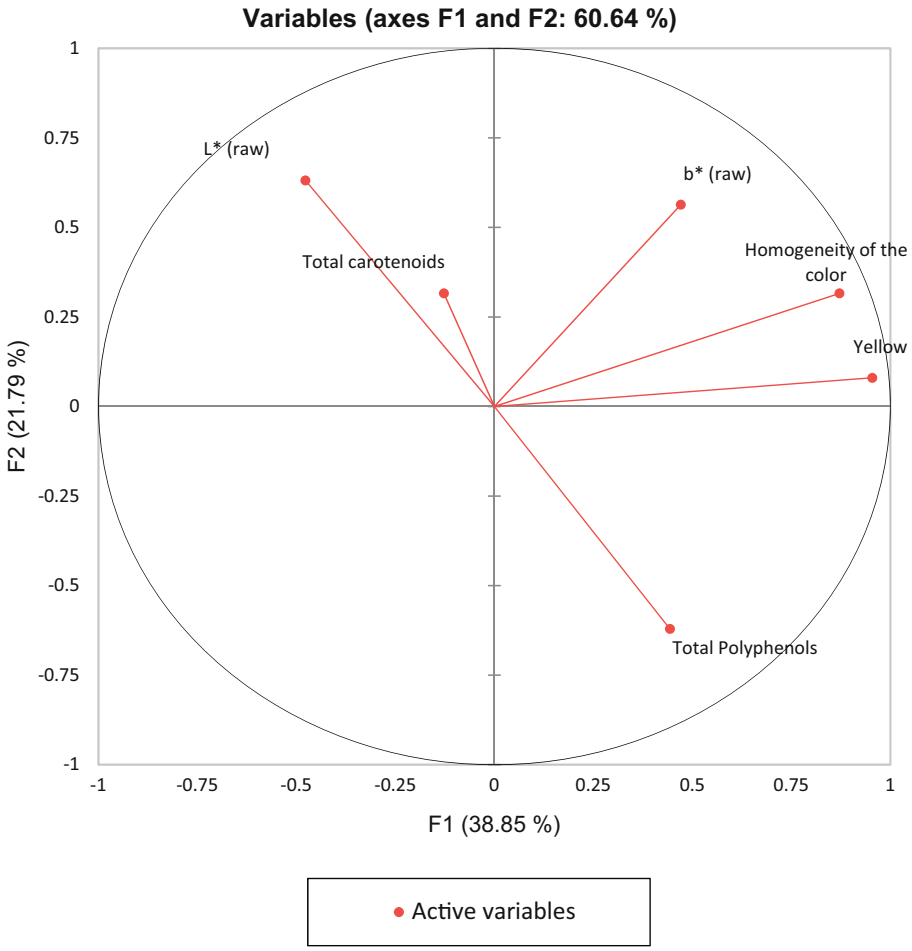

Figure 2. Principal component analysis of instrumental and biochemical indicators of sensory color and its uniformity of selected EAHCB genotypes.

and therefore be appreciated by consumers. However, the present study showed that this was not the case. This could be a result of the presence of other components, especially polyphenols which cause oxidation, masking the yellow color. Research conducted by Taranto *et al.*[36] demonstrated that polyphenols were correlated with oxidative reactions that cause discoloration in fruits, including bananas, whereas Nowakunda *et al.*[30] and Nowakunda *et al.*[31] reported that condensed tannins were correlated with poor color and astringency taste in cooked matooke improved hybrids, leading to their rejection.

End-user acceptable EACHB genotypes could be selected at early evaluation stages using instrumental color indicator (i.e. the *b** coordinate), textural hardness, in addition to the bunch and finger characteristics (Table 1). Either color, textural or bunch characteristics can individually result in rejection of EACHB. Hybrids can have the preferred yellow color but lack the soft texture. Such hybrids should be discarded in the breeding pipeline. It is therefore important to use all the three indicators simultaneously during selection. These are easy to select for, but it is imperative that thresholds below which users reject the hybrids be determined. Alhough it would considerably less expensive and faster to predict the quality indicators on raw samples, the present study also showed that some of the quality characteristics such as color are difficult to predict from raw samples as a result of other compounding reactions during preparation and cooking.

Breeders of the EACHB can select user-preferred hybrids by measuring hardness of raw fruit pulp using a texturometer and color using a chromameter. In the laboratory, the instrumental measurements for color and hardness can be complemented with biochemical components amylose/amylopectin and polyphenol content using iodometric and Folin–Ciocalteu methods, respectively, once the thresholds are known. Also, the desired traits can be tagged to correlated genes and molecular markers for the user-preferred characteristics developed for breeding programs. It is acknowledged that the correlations between instrumental hardness and firmness in mouth, cohesiveness and firmness in the mouth, and adhesiveness and firmness in the mouth were moderate ($r = 0.55–0.64$) and that the results need further validation. This method could be a handy tool in the selection of improved hybrids with characteristics that fit into the socio-economic conditions of the target user.

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AUTHOR CONTRIBUTIONS

KN, BU and EN were responsible for conceptualization. KA, EK, CB and AB were responsible for data curation. EK, KN, KA and HC were responsible for formal analysis. DD was responsible for funding acquisition. KN, EK, KA and MA were responsible for investigations. LF, KA, PM, CB and HC were responsible for methodology. KN and DD were responsible for project administration. KN and DD were responsible for resources. KN and DD were responsible for supervision. KN was responsible for writing the original draft. KN, EN, BU and WT were responsible for reviewing and editing.

DATA AVAILABILITY STATEMENT

Data openly available in a public repository that issues datasets with DOIs.

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