Research Article

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Relation between quantitative descriptive analysis and textural analysis of boiled plantain

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Abstract

BACKGROUND: Inadequate consideration of textural quality in conventional breeding pipelines of plantains (from breeders to end-users) results in limited impact. Knowledge of the textural quality characteristics of boiled plantain, as preferred by end-users, could help improve the adoption of new clones when these traits are selected for breeding. The present study aimed to evaluate the relationship between instrumental and sensory texture attributes of boiled plantain genotypes. Consumer testing (Just About Right and Check All That Apply tests), sensory quantitative descriptive analysis (QDA), instrumental texture profile analysis (TPA) and penetrometry were conducted with nine accessions: three landraces and six plantain-like bred hybrids.

RESULTS: Landraces were considered just-about-right by more than 45% of people for all the sensory attributes (humidity, sweetness, color and firmness), described by characteristics such as smooth on sight, attractive, mealy, firm, plantain taste and yellow. Color and firmness were the most highly scored attributes by panelists for the landraces. Penetrometry discriminated among genotypes better than TPA. Hardness, gumminess, resilience and chewiness were the most discriminatory attributes for TPA, whereas hardness and area under the curve were the most discriminatory attributes for penetrometry. No correlation was found between penetrometry and sensory texture of boiled plantain. For TPA, negative correlations were found between sensory humidity and hardness, as well as between sensory firmness and resilience, whereas a positive correlation was found between resilience and sensory humidity.

CONCLUSION: Combining QDA and texture measurements can make the selection of plantain hybrids more effective and improve the adoption of new varieties.

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

Keywords: consumer testing; texture profile analysis; penetrometry; efficient breeding; variety adoption

INTRODUCTION

Plantain belongs to the Musaceae family and is cultivated in many tropical and sub-tropical zones of Africa, Asia, and Central and South America. Although it is an important staple food in Africa, some cultivars cannot be identified by morphological characteristics alone.[1] In West and Central Africa, plantain is cooked or processed in different ways and can be used either when unripe or ripe. Some studies identified boiled plantain as the most consumed form of plantain in Cameroon.[2–4]

Varietal improvement has largely been carried out considering agronomic performance and tolerance to pests and diseases, but less attention has been paid to consumers' preferences.

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Thus, very few plantain-like bred hybrids have been adopted worldwide.[5] Considering the increasing demand for plantain, it is essential to develop new clones that will be better adopted by end-users.

There are various methods to assess the quality of a product. The visual appearance can be evaluated through color scales or the Munsell color system, which describes colors based on hue, value and chroma.[6] Sound can be evaluated using a trained panel or the acoustic envelope technique, which measures the amplitude and frequency of sounds.[7] The flavor profile method can assess different flavor attributes using a structured questionnaire,[8] while mouthfeel can be evaluated through sensory profiling by trained panel.[9] Texture can be evaluated through sensory profiling, instrumental analysis or consumer testing, using methods such as texture profile analysis (TPA), which measures firmness, springiness, cohesiveness, chewiness and adhesiveness.[10]

Even though sensory analysis provides detailed information about the sensory properties of a product, helps to optimize product formulation, and can be used to identify the key drivers of consumer liking and preferences, it is rather time-consuming, influenced by the expertise and experience of the panelists, and affected by environmental factors.[8,9,11] Texture analysis on the other hand provides objective and quantitative data on the physical properties of a product and can be used to monitor and control product consistency and quality over time. However, its results may not always correspond to consumer preferences, and may not provide information on other sensory attributes, such as flavor and aroma.[10–12]

To better assess the quality of boiled plantain, its key attributes need to be identified. A thorough evaluation of a new product requires assessing its sensory profile. Relating that profile to instrumental measurements can improve precision and speed of evaluation because the detailed assessment of a new product requires determining its sensory profile, and then relating it to the instrumental texture.[13]

TPA, one of the many applications of a texture analyzer, is an objective method of analyzing the applied aspects of the textural characteristics of food products, crucial to developing a product that meets consumer expectations.[14] Recent studies highlighted preferred quality characteristics of plantain cultivars in an attempt to improve the adoption of newly bred hybrids.[15–17] Kouassi *et al.*[18] designed robust predictors of boiled plantain firmness, chewiness, mealiness, moistness and sweetness using easy-to-measure physicochemical and textural tests. However, the elaboration of a complete boiled plantain product profile requires the integration of consumer preferences in addition to both sensory and instrumental texture analysis to enable the establishment of correlations between these parameters and hence accelerate the acceptance of new bred hybrids.

The quantitative descriptive analysis (QDA) approach has been recognized as a tool for the measurement of sensory attributes of various food products,[19] as a basis for developing sensory profiles of foods. Therefore, the present study aimed to assess the relationship between instrumental texture and sensory characteristics of boiled plantain with consideration of consumer preferences from nine plantain accessions in Cameroon.

MATERIALS AND METHODS

Locations

Consumer testing was carried out in Njombe and Mbangain the Moungo division in Cameroon, areas of high production and consumption of plantain. Consumer testing was conducted with a total of 123 untrained consumers. QDA and physiochemical analyses were carried out at CARBAP's (Centre Africain de Recherches sur Bananierset Plantains) Post-Harvest Technology Laboratory based in Njombe, Cameroon.

Plant material

Plantain bunches were obtained from nine accessions harvested at optimum physiological maturity from IITA (International Institute of Tropical Agriculture) experimental plots in Mbalmayo (elevation ~640 m) in the Centre region; from CARBAP experimental plots in Bansoa (elevation ~1300 m) in the West region, and from Njombe (elevation ~80 m) in the Littoral region of Cameroon. These accessions include three landraces (*Batard*, *Big Ebanga* and *Kelong Mekintu*), four IITA bred hybrids (PITA 14, PITA 21, PITA 23 and PITA 27) and two CARBAP bred hybrids (*CARBAP 969* and *CARBAP K74*). Some characteristics of these accessions as well as their photographs are highlighted in Table 1 and Fig. 1, respectively. As a result of a lack of sufficient plantain bunches, IITA-bred hybrids could not be used for consumer testing.

Sensory evaluation

Sample preparation

Plantain fruits from the second and third hands were selected, washed, peeled, weighed and soaked in water to prevent oxidative browning. The quantity of water was based on pulp:water ratio of 1:4. This water was brought to boil in an aluminium pot (width, 30 cm; height, 16 cm; thickness, 0.4 cm) using butane as the heat source. The pulps were introduced once the water started boiling, and their boiling times were determined following previous work at the laboratory. For bred hybrids, boiling was completed after 45 min, when the pulp is sufficiently cooked, whereas landraces were cooked for 60 min. After boiling, plantain pulps were drained and kept in a thermos flask containing hot water (temperature ≥ 95 °C) to retain a temperature between 55 and 60 °C before sensory evaluation. Plantain clones were cooked in triplicate.

Consumer testing

A total of 123 untrained consumers tested two landraces (*Batard* and *Big Ebanga*) and two bred hybrids (*CARBAP K74* and *CARBAP 969*) of plantain. Fruits were cut into cylindrical slices (height, 2 cm), put in disposable plates and presented to the consumers in a monadic manner. After tasting each sample, the consumer was asked to rinse their mouths with mineral water before tasting the next sample. The temperature of the plantain slice was monitored with a kitchen thermometer before testing and was maintained between 50 and 60 °C.

The consumers, mainly from Cameroon, were invited to participate in the consumer test. They were asked to answer a questionnaire, give personal information (gender, country of residence, ethnic group, education, marital status, etc.) and provide consumption habits of boiled plantain (frequency, mode of consumption, when and with what other ingredients).The method used included a hedonic test, a Just About Right (JAR) test and a Check All That Apply (CATA) test.[20]

QDA

QDA was used to measure the intensity of the sensory characteristics of the plantain. The QDA was carried out on the nine plantain genotypes. The panel was composed of 10 trained panelists (three women and seven men). These panelists were evaluated using the protocols developed by Maraval *et al.*[21]

Table 1. Average fruit characteristics of the plantain accessions evaluated in the present study

Accessions	Fruit origin	Cultivar type	Fruit weight (g)	Pulp weight (g)	Peel weight (g)	Pu/pe* ratio	Fruit grade (cm)	Fruit length (cm)
CARBAP 969	Bansoa	Bred hybrid	212.6 (4.4)	125.8 (1.8)	85.0 (5.3)	1.5 (0.1)	4.0 (0.1)	21.3 (1.5)
CARBAP K74	Bansoa	Bred hybrid	216.9 (18.0)	135.8 (13.3)	80.2 (5.1)	1.7 (0.1)	3.8 (0.1)	22.0 (1.0)
PITA 14	Mbalmayo	Bred hybrid	115.4 (10.0)	70.4 (3.8)	44.0 (7.6)	1.6 (0.1)	3.3 (0.1)	19.0 (1.0)
PITA 21	Mbalmayo	Bred hybrid	121.7 (12.7)	65.7 (4.2)	55.2 (8.8)	1.2 (0.1)	3.6 (0.1)	20.7 (1.5)
PITA 23	Mbalmayo	Bred hybrid	105.5 (6.7)	57.1 (3.9)	51.1 (1.4)	1.1 (0.1)	3.3 (0.1)	17.0 (1.0)
PITA 27	Mbalmayo	Bred hybrid	119.6 (6.01)	74.6 (3.3)	44.7 (4.0)	1.7 (0.1)	3.2 (0.2)	17.3 (0.6)
Batard	Njombe	Landrace	281.9 (73.9)	173.3 (50.7)	107.2 (22.8)	1.6 (0.1)	4.3 (0.2)	25.3 (2.5)
Big ebanga	Njombe	Landrace	215.3 (8.1)	131.1 (4.3)	83.4 (4.0)	1.6 (0.0)	3.8 (0.2)	23.3 (0.6)
Kelong mekintu	Njombe	Landrace	168.4 (6.6)	108.8 (3.1)	58.9 (3.8)	1.9 (0.1)	3.3 (0.1)	18.7 (1.2)

Note: SD values are shown in parenthesis.
*Pu/Pe, pulp to peel ratio.

For pre-selection/recruitment of panelists, panelists are recruited voluntarily via a straightforward application or internally following a call from the laboratory. In general, if the panel should consist of *X* subjects, it is advisable to recruit and train at least 1.5*X* people. Care should be taken during recruitment to ensure there is an equal balance between men and women as well as good age distribution among the potential panelists (from 18 to 60 years).

For training and selection of panelists, panelists are trained to identify and describe sensory attributes using a standardized vocabulary. Training sessions are conducted using reference samples with known sensory properties. The main sensory tests performed to train and select the panel include basic flavor and sensation recognition test, basic flavors classification test, and the threshold test for perception of basic flavors and sensations.

For calibration of panelists, the selected panelists are calibrated to ensure consistency in their sensory evaluations through five sessions, including generating a vocabulary, drawing up the tasting form, using the scale, individual notation on a scale and panel performance.

For conduction of descriptive tests, tests are conducted to evaluate the sensory properties of food products, using a structured evaluation form that includes a list of sensory attributes and a rating scale for each attribute. Panelists evaluate the intensity of each sensory attribute using the rating scale.

For data processing, the data collected from descriptive tests are analyzed to identify the sensory properties that distinguish products from one another. Statistical analyses of data are carried out using XLSTAT (https://www.xlstat.com for analysis of variance and principal component analysis (PCA).

Panel performance was monitored using the methodology described by Bugaud *et al.*[22]:

- Inputting and sorting of data: in an Excel (Microsoft Corp., Redmond, WA, USA) sheet, data related to the samples (name, code), the panelist (name, code, score) and tasting sessions (repetition and session numbers) are recorded. These data are sorted by session numbers, then by sample codes;
- Evaluation of panel repeatability: this is carried out using a series of steps. However, the repeatability of panelists is optimized under four conditions: (i) the difference (in absolute value) between two observations is less than or equal to 3 on a scale of 0 to 10; (ii) if a panelist was not repeatable for an attribute in a session, then the scores made by that panelist for that attribute are dropped for all products in that session; (iii) a panelist who has been repeatable for an attribute at more than 50% of all sessions is repeatable for that attribute; and (iv) a panelist who is not repeatable for more than 50% of the attributes is eliminated.
- Evaluation of panelists' agreement with the panel and data cleaning: the agreement of the panelists to the panel is optimized under three conditions: (i) the agreement is effective if the difference (in absolute value) for a given product between the average score of the panel and that of each panelist is less than or equal to three on a scale of 0 to 10; (ii) if, for an attribute, more than 50% of a panelist's data does not agree with the panel, then that panelist's data for that attribute is discarded; and (iii) a panelist who is not in agreement with the rest of the panel for more than 50% of the attributes is removed.
- Preparation of the final table: the final mean table with the average values obtained by the panel for each product, each attribute on a scale of 0 to 10, is elaborated. This table will be used for graphical (radar) and statistical analysis (PCA, linear regressions).

The boiled plantain traits studied were sweetness, firmness, humidity, yellow color and overall acceptability (Table 2). They were assessed using a rating scale from 0 to 10 (0 = lowest score and 10 = highest score). For the QDA, the same tasting protocol as for consumer testing was used.


Photo 1. *CARBAP 969* (PBH)


Photo 2. *CARBAP K74* (PBH)


Photo 3. *PITA14* (PBH)


Photo 4. *PITA21* (PBH)


Photo 5. *PITA23* (PBH)


Photo 6. *PITA27* (PBH)


Photo 7. *Batard* (PL)


Photo 8. *Big Ebanga* (PL)


Photo 9. *Kelong Mekintu* (PL)

Figure 1. Bunches of plantain varieties used within the framework of the present study.

Texture analysis

Instrumental texture parameters of boiled plantain pulps were measured by penetration (penetrometry) and double compression (TPA) using a Texture Analyzer (TA-XTplusC; Stable Microsystems Ltd, Godalming, UK). The protocol used was the one developed by Ngoh Newilah & Kendine Vepowo.[23] For this, fully cooked plantain pulps were drained and kept in a thermos box. A boiled pulp was removed, put in a tray and cut in the middle section using a double-blade knife. All texture measurements were made at temperatures ranging between 55 and 60 °C, measured using a digital thermometer. For penetrometry, a 40° conical Perspex probe penetrated the boiled plantain slice (2 cm long with the dorsal side facing the probe) at a constant speed (1 mm s^{-1}) to a depth of 10 mm. The maximum force applied during the measurement was recorded. Using a hollow cylindrical rod, cut plantain pulps were extruded (width, 2.9 cm; height, 2 cm) and placed on the plate of the texture analyzer for TPA. Two compression cycles, each corresponding to a strain of 30% were carried out at a constant speed (1 mm s^{-1}) using a 35-mm diameter cylinder probe. The textural attributes measured include hardness, cohesiveness, adhesiveness, springiness, gumminess and chewiness.

TPA measurements were carried out on all clones, whereas penetrometry could not be performed for *CARBAP 969* because of a shortage of samples. Each sample underwent two cooking replicates with at least eight readings per replicate.

Physicochemical analyses

Total soluble solids (TSS) was performed using a Hand-held refractometer [BRIX REF113 0-32 ATC; Federal Hospitality Equipment (F.E.D), Sydney, NSW, Australia]. Total titratable acidity (TTA) was assessed manually by titration with 0.1 N sodium hydroxide until the endpoint of the reaction, characterized by the change in color of the phenolphthalein indicator (from colorless to pink/red). Dry

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Table 2. Boiled plantain sensory attributes used in the QDA

Category	Descriptor	Definition	How to measure	Scale
Flavour	Sweetness	Sweet basic taste	Not determined	0: Not sweet at all 10: Very sweet
Texture	Firmness	Does not fall apart quickly, holds well, which is neither soft nor hard.	Resistance with the fork when cutting. Resistance in the mouth neither too easy to chew nor too hard to chew.	0: Not very firm: soft 10: Very firm: hard
	Humidity	When the plantain slice is waterlogged	If it is not very humid, it makes you salivate a lot in the mouth, you have to chew it for a long time. If it is too wet it is soft, feeling of chewing a little water, no resistance to chewing	0: Very dry 10: Very humid (contains too much water)
Visual	Yellow colour	Color of whole plantain slice.	Look at the whole slice of plantain and average the colors if it is not homogeneous	0: Cream 2: Very pale yellow 4: Pale yellow 6: Yellow 8: Bright yellow 10: Yellow–orange
Overall quality		Represents the objective global judgment on the plantain.		0: Low quality 10: Very high quality

matter content (DMC) of cooked plantain pulps was assessed directly on the fresh sample in an oven at 105 °C until constant weight. All these protocols were reported by Dadzie and Orchard,[24] with analyses conducted in triplicate.

Statistical analysis

One-way analysis of variance was carried out to identify significant differences in overall liking/attribute scores between the boiled plantain samples tested by the consumers and the panelists. Segmentation was performed via hierarchical cluster analysis (Ward's method) to separate consumers into groups of similar acceptance. Multiple pairwise comparisons were applied using Tukey's test with a confidence interval of 95%. For each boiled plantain sample, the number of consumers who judged each specific characteristic either just-about-right, too weak or too strong were counted, and the percentage of consumers was determined. PCA (covariance) were used to describe the relationships between frequencies of citation of CATA sensory/perception characteristics and the mean overall liking scores for each boiled plantain sample. Statistical analyses of physicochemical, consumers' testing and QDA-related data were performed using XLSTAT 2014.[25] Exponent Connect Software, version 8.0.9.0,26 was used for texture analysis, whereas JMP, version 16,[27] was used for analyzing texture-related data. Pearson correlation coefficients at 5% threshold were determined for this set of data and linear regressions were applied to predict the physicochemical and textural properties with QDA parameters for which the corresponding JAR values were at least 50% to obtain acceptable threshold values.

RESULTS

Socio-demographic characteristics of respondents

The number of participants per locality in the consumer study was almost identical (48.8% in Njombe and 51.2% in Mbanga), with men representing 57.7% (Table 3). The main tribe was *Bamileke* (60.7%), followed by *North westerner* (10.7%). Most respondents were married (60.2%), a majority had attended secondary education and were either artisans, employees or traders (22%). Boiled plantain was most of the time consumed several times a week (31.7%), either with vegetables (61.8%) or with a sauce (51.2%), particularly in the evening (73.2%) (Table 3).

Consumer testing and organoleptic characteristics of boiled plantain

Based on the evaluation by the 123 untrained consumers, the overall likings of the boiled plantain samples were significantly different at $P < 0.05$ (Table 4). *Batard* (6.9/10) and *Big ebanga* (6.6/10) were the most liked boiled plantain samples. The *CARBAP 969* sample was liked slightly, wheresas *CARBAP K74* was neither liked nor disliked (5.3/10).

An agglomerative hierarchical clustering analysis of the mean overall liking scores enabled the identification of three groups of consumers: All likers, *CARBAP 969* and *CARBAP K74* dislikers, and *CARBAP K74* dislikers (Fig. 2).

Percentage responses for color, firmness, humidity and sweetness of boiled plantain samples using a JAR scale are represented in the Supporting information (Fig. S1). This *descriptor diagnostic* may help understand why consumers like or dislike a particular boiled plantain sample. The majority of consumers were satisfied with the four sensory characteristics, color, sweet taste, firmness and humidity of *Batard* and *Big ebanga* boiled samples, except for the sweetness of *Big ebanga*, where only 48.8% of consumers liked it. *CARBAP 969* showed acceptable levels for humidity, as well as slight deficiencies for sweetness and firmness (44.7% JAR), but was clearly deficient for color. More than 60% of respondents disliked *CARBAP K74* for each of the four characteristics assessed.

PCA was used to summarize the relationships between the CATA sensory characteristics, boiled plantain samples and the mean overall liking of each product scored by all the consumers (see Supporting information, Fig. S2). The PCA plot explained 96.5% of the variance of the sensory characteristics, and the first and second axes accounted for 82.9% and 13.6%, respectively. Most of the variance was explained by the first axis. The loading of sensory characteristics on the PCA plan shows that

Table 3. Distribution of consumers surveyed according to demographic differences and consumer attitudes to boiled plantain

Demographic criteria and consumer attitudes	Categories	Percent by criteria (123 consumers)
Locality	Njombe	48.8
	Mbanga	51.2
Gender	Female	42.3
	Male	57.7
Age (years)	18–25	9.8
	26–35	35.8
	36–45	21.1
	46–55	20.3
	≥ 56	13.0
Ethnicity	Bamileke	60.7
	Northwesterner	10.7
	Ewondo	3.3
	Balong	4.9
	Mbo'o	2.5
	Duala	7.4
	Northerner	2.5
	Yabassi	4.1
	Others	4.1
Education	No education	3.3
	Primary education	24.4
	Secondary education	56.9
	Higher education	15.4
Marital status	Single	34.1
	Married	60.2
	Widower	5.7
Occupation	Student	3.3
	Artisanship	28.5
	Civil servant	4.1
	Trading business	22.0
	Employee	26.8
	Unemployed	9.8
	Retired	2.4
	No response	3.3
Consumption frequency	Daily	5.7
	Several times a week	31.7
	One time a week	28.5
	Several times a month	26.0
	One time a month	2.4
	Rarely	5.7
Main consumption form*	With a sauce	51.2
	With vegetables	61.8
	With legumes	34.1
	With meat or roasted fish	20.3
	Others	5.7
Period of consumption*	Morning (breakfast)	28.5
	Noon (lunch)	57.7
	Evening (dinner)	73.2
	Between meals	6.5

*One or more responses were given.

axis F1 was mainly explained positively by the following terms: smooth on sight, attractive, mealy, firm, good smell, plantain taste, yellow, hard and dry related to the most liked boiled plantain samples derived from *Batard* and *Big ebanga*; and negatively by the terms: taste of sap, pale color, moist, soft and odorless related to the least liked boiled plantain sample (*CARBAP K74*).

Physicochemical composition, sensory and texture characteristics of boiled plantain

Physicochemical composition

The physicochemical characteristics of boiled plantain samples revealed significant differences ($P < 0.05$) in all the parameters analyzed (Table 5). *Batard* presented the highest TTA values, followed by *PITA 27*. All bred hybrids, except *PITA 23*, presented significantly higher values compared to the landraces *Big ebanga* and *Kelong Mekintu*. Similarly, *Batard* recorded significantly higher values for TSS, followed by *Big ebanga* and *CARBAP K74*, which displayed TSS of more than 10.0°Brix. The lowest TSS was recorded by *PITA 23*. In addition, DMC was significantly higher in landraces, with *Batard* exhibiting the highest value, in contrast to the significantly lower values presented by *PITA 21* and *PITA 27*.

Sensory attributes of boiled plantain

The ranking of the various attributes of boiled plantain samples using a scale from 0 to 10 revealed that, across genotypes, sweetness, humidity and color scored less than 5 (Table 6). Firmness was significantly higher (≥ 6.0) for *Batard*, *Kelong mekintu* and *PITA 23*, whereas *PITA 21* recorded the least firmness. A reverse trend was observed for Humidity. Landraces presented the highest mean scores (≥ 5) for color, with *Kelong mekintu* recording the highest value. The landraces scored lowest for sweetness, whereas *CARBAP 969* exhibited the highest mean score (3.6). The overall acceptability was significantly higher (≈8) for landraces (*Batard*, *Kelong mekintu* and *Big ebanga*), with *CARBAP 969* being the only bred hybrid recording a mean score that was not statistically different from landraces. *PITA 21* was the least accepted boiled plantain sample.

The mapping of the sensory attributes and the overall acceptability during QDA revealed that the PCA plot explained 86.5% of the variance of the sensory attributes (see Supporting information, Fig. S3). Most of the variance was explained by the first axis (67.2%). The loading of these sensory attributes on the PCA plan shows that axis F1 was mainly explained positively by the attributes such as overall acceptability, firmness and color, related to the most liked boiled plantain samples, which were exclusively landraces (*Batard, Big ebanga* and *Kelong mekintu*). Axis F1 was mainly explained negatively by the term humidity related to the least liked boiled plantain sample (*PITA 21*). The attribute sweetness was only explained by the axis F2 and is related to *CARBAP 969* boiled plantain sample.

Table 4. Mean overall liking scores for boiled plantain samples tested

Boiled plantain samples	Mean overall liking scores (123 consumers)*	Groups**		
Batard	6.9	A		
Big ebanga	6.6	A	B	
CARBAP 969	6.3		B	
CARBAP K74	5.3			C

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

Instrumental texture analysis of boiled plantain

Boiled plantain texture attributes for each type of test are displayed in Table 7. Significant differences were observed for all the attributes among the various clones. TPA revealed that *Batard* exhibited the highest values for hardness, gumminess and chewiness; *CARBAP K74* recorded the highest values for springiness and adhesiveness; *PITA 21* was the most resilient; and *Big ebanga* was the most cohesive clone. Penetrometry measurements, on the other hand, showed that *Big ebanga* was the hardest clone and *PITA 21* had the highest distance at F_{max}, whereas *CARBAP K74* presented the highest area under the curve (see Supporting information, Fig. S4).

Discriminant analysis between TPA and penetrometry

Within the framework of the present study, the instrumental methods used to assess texture characteristics of boiled plantain genotypes (TPA and penetrometry) discriminated between the genotypes (see Supporting information, Fig. S5). However, penetrometry was more discriminant than TPA. The concentric circles found in each plot represent the various genotypes, with various overlappings depending on how close the genotypes are to each other for an attribute. For penetrometry, *CARBAP K74*, *Batard* and

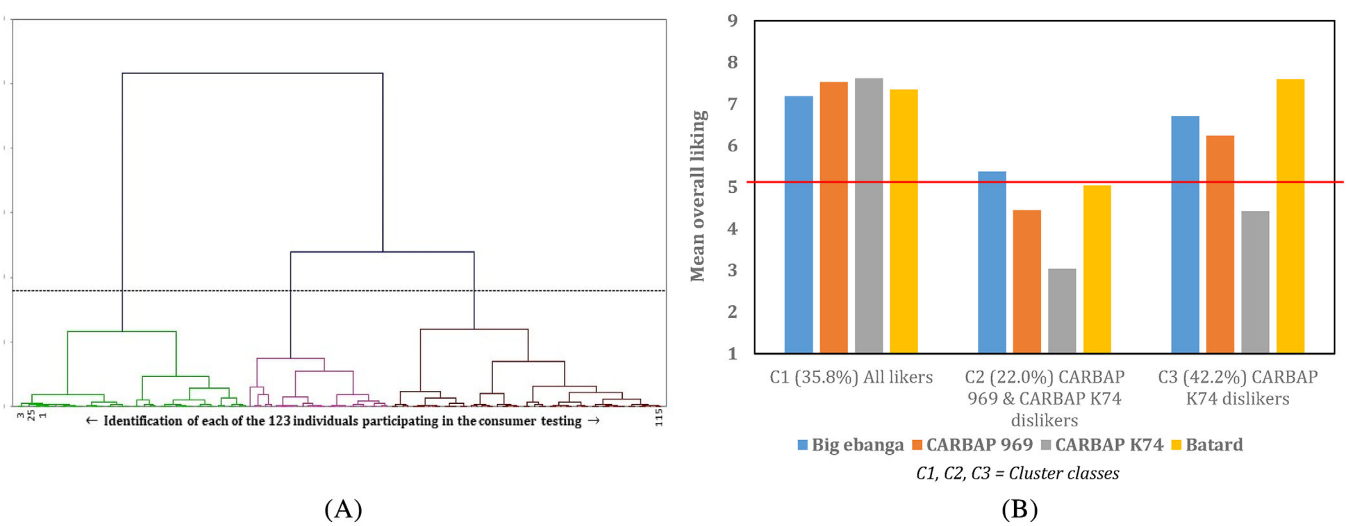

Figure 2. Clustering of the consumers based on their (A) overall liking and (B) mean overall liking of the boiled plantain samples by consumer clusters.

Table 5. Physicochemical characteristics of boiled plantain per accession prior to QDA

Accessions	TTA (mEq per 100 g)	TSS (°Brix)	DMC (%)
CARBAP 969	511.1 ± 38.5 bcd	10.0 ± 1.2 bcd	30.4 ± 2.5 abc
CARBAP K74	511.1 ± 38.5 bcd	12.6 ± 0.7 bc	30.6 ± 4.2 abc
PITA 14	577.8 ± 38.5 abc	6.8 ± 0.9 de	30.1 ± 3.2 abc
PITA 21	577.8 ± 38.5 abc	4.6 ± 0.6 ef	26.5 ± 0.7 c
PITA 23	422.2 ± 38.5 d	2.4 ± 0.4 f	31.1 ± 1.0 abc
PITA 27	622.2 ± 77.0 ab	12.0 ± 0.9 bc	26.9 ± 1.8 bc
Batard	666.7 ± 66.7 a	16.4 ± 2.8 a	33.7 ± 1.8 a
Big ebanga	444.4 ± 38.5 cd	13.0 ± 1.6 ab	32.9 ± 1.5 ab
Kelong mekintu	422.2 ± 38.5 d	9.2 ± 0.4 cd	33.4 ± 0.3 a
AVERAGE	528.4 ± 45.9	9.7 ± 1.1	30.6 ± 1.7

Note: Mean ± SD values with the same lowercase letters in the same columns are not significantly different ($P < 0.05$, Tukey's test).
Abbreviations: DMC, dry matter content; TSS, total soluble solids; TTA, total titratable acidity.

Big ebanga were isolated, whereas, for TPA, the genotypes presented numerous overlappings. Regardless of the method used to discriminate between good, intermediate and poor genotypes for boiled plantain, three clusters were obtained (see Supporting information, Fig. S6). Genotypes *Kelong mekintu* and *PITA 27* were together in both protocols. *Big Ebanga* and *Batard* were clustered together by TPA, but not by penetration. *CARBAP K74* is uniquely clustered separately by penetration. *PITA 14*, *PITA 21* and *PITA 23* are all clustered together in both protocols.

Correlation between instrumental texture analysis and sensory analysis

PCA plots of the combination of instrumental and sensory texture revealed that 83% of the variance of the attributes was accounted for, with 61.1% and 21.8% representing the first and second components (see Supporting information, Fig. S7), respectively. *PITA 14*, *PITA 27* and *PITA 21* were closely related bred hybrids and they were associated with resilience and sensory humidity. Humidity (wetness) refers to the mouthfeel of a moist texture rather than dryness and influences boiled plantain chewing. *CARBAP K74* is a plantain-like bred hybrid associated with a springy, hard and adhesive texture, and was uniquely clustered separately from other genotypes by penetration attributes and was not preferred by consumers. *Big ebanga* and *Batard* are landraces discriminated by penetrometry, but not by TPA. Both genotypes were associated with a cohesive, chewy, gummy, hard and sensory firm texture, but not humid, and were considered more preferred by consumers than bred hybrids. The plantain-like bred hybrid *PITA 23* and the landrace *Kelong mekintu* were close in texture but were not associated with regard to sensory humidity or firmness. They may be considered to be of intermediate preference by consumers (see Supporting information, Fig. S7). The only significant correlation between penetration and TPA attributes (see Supporting information, Fig. S8) concerned penetration hardness and TPA chewiness ($r^2 = 0.63$, $P = 0.048$). There were several significant correlations between TPA and the sensory texture of boiled plantain (Table 8), as shown below:

- TPA hardness and sensory humidity ($r = -0.87$)
- TPA resilience and sensory firmness ($r = -0.74$)
- TPA resilience and sensory humidity ($r = 0.92$)
- TPA springiness and sensory firmness ($r = -0.77$)
- TPA gumminess and sensory humidity($r = -0.76$)

There were no significant correlations between penetration and sensory texture of boiled plantain.

Prediction of physicochemical and texture attributes using QDA data

The determination of some threshold values of boiled plantain quality traits was carried out using data obtained from JAR, QDA, texture and biophysical analyses. Pearson correlation coefficients were obtained from these data at 5% threshold (Table S1) and plots (see Supporting information, Fig. S9) were drawn to determine r^2 values between JAR and QDA data. Only the plots of firmness and color were found to show a linear relationship ($r^2 > 0.5$). Hence, these traits were considered for the determination of threshold of some biophysical values. Based on the maximum JAR data obtained (65%), the acceptable value was set to 50% and taking into consideration the graphs of firmness and color, the corresponding QDA values are 5.7 for firmness and 5.0 for color. Using these acceptable values, regression equations and threshold values were determined. The acceptable threshold values of studied boiled plantain traits were: DMC > 32.03%; TPA hardness > 8737.31 g; TPA resilience > 291.56%; and TSS > 13.9° Brix (Table S2).

DISCUSSION

The high overall acceptability scores obtained by *Batard* and *Big ebanga* compared to *CARBAP 969* and *CARBAP K74* during consumer testing could be explained by the fact that the former are landraces and consumers are familiar with them, unlike the latter, which were introduced during the testing. Ngoh Newilah *et al.*[18] obtained similar results with restaurant cooks who preferred *Batard* and *Big ebanga* over *CARBAP K74* in the cities of Douala and Bafoussam in Cameroon. The clustering of the consumers with respect to the overall liking supports the evidence that landrace varieties were preferred over plantain-like bred hybrids: two clusters out of three were composed of *Bred hybrid dislikers* or *CARBAP K74 dislikers*. Furthermore, JAR analysis revealed that the majority of consumers were satisfied with the four sensory characteristics of *Batard* and *Big ebanga*, with the JAR percentages always greater than 45% (see Supporting information, Fig. S1). The *Not yellow enough* perception of the color of bred hybrids by most consumers could be attributed to the relatively low carotenoid content of these clones compared to the landraces.[28] Moreover, the fact that *CARBAP K74* was *Not firm enough* and

Table 6. Mean attribute scores for boiled plantain samples during QDA

Accessions	Firmness	Humidity	Sweetness	Colour	Overall quality
CARBAP 969	5.4 bc	5.4 ab	4.0 a	4.3 bc	7.8 ab
CARBAP K74	4.7 cd	5.4 ab	1.8 c	4.8 b	6.6 c
PITA 14	5.3 bc	5.3 abc	2.3 bc	4.9 b	7.1 abc
PITA 21	3.6 d	6.0 a	1.8 c	3.3 c	5.3 d
PITA 23	6.0 ab	4.6 bcd	2.2 bc	4.7 bc	7.0 bc
PITA 27	5.6 abc	4.8 bcd	2.3 bc	4.5 bc	7.1 bc
Batard	6.7 a	3.6 d	1.8 c	5.0 ab	7.9 ab
Big ebanga	5.6 abc	4.2 cd	1.8 c	5.2 ab	7.8 ab
Kelong mekintu	6.5 ab	4.4 bcd	2.8 b	6.3 a	8.2 a
AVERAGE	5.5	4.9	2.3	4.8	7.2

Note: Means with the same lowercase letters in the same columns are not significantly different ($P < 0.05$, Tukey's test).

Table 7. Mean texture attributes of boiled plantain samples

	TPA parameters							Penetrometry parameters		
Accessions	Hardness (g)	Resilience (%)	Springiness (%)	Adhesiveness (g.s)	Cohesiveness	Gumminess	Chewiness	Hardness (g)	Distance at F_{max} (mm)	Area under the curve (g.s)
CARBAP 969	6794.3 ± 1848.1 cd	95.1 ± 17.4 cd	90.2 ± 11.6 b	−229.5 ± 128.9 ab	0.2 ± 0.1 b	1061.4 ± 346.2 bc	941.5 ± 273.5 cd	*NA*	*NA*	*NA*
CARBAP K74	7635.4 ± 1818.4 c	109.0 ± 24.8 c	102.0 ± 21.5 a	−132.5 ± 133.6 a	0.2 ± 0.0 b	1226.7 ± 368.9 b	1235.8 ± 392.8 bc	422.3 ± 50.4 a	4.3 ± 0.9 c	4598.4 ± 519.7 a
PITA 14	3356.0 ± 452.5 f	151.1 ± 22.5 b	86.4 ± 8.6 b	−393.6 ± 234.0 bc	0.1 ± 0.0 c	320.4 ± 68.3 d	264.2 ± 62.8 e	58.5 ± 15.4 de	6.6 ± 1.9 ab	384.7 ± 112.5 ef
PITA 21	2929.3 ± 737.7 f	212.4 ± 52.8 a	89.7 ± 11.2 b	−376.9 ± 249.9 abc	0.1 ± 0.0 c	300.1 ± 98.8 d	244.0 ± 67.7 e	49.4 ± 13.4 e	7.7 ± 1.8 a	281.4 ± 73.2 f
PITA 23	5992.8 ± 590.4 de	112.8 ± 19.8 c	62.2 ± 9.8 d	−1051.4 ± 544.9 d	0.1 ± 0.0 c	543.4 ± 179.5 cd	337.6 ± 138.5 e	84.0 ± 29.1 cd	5.5 ± 0.8 bc	560.7 ± 174.8 de
PITA 27	5567.9 ± 1852.5 e	108.0 ± 31.1 c	82.5 ± 12.6 bc	−188.4 ± 132.4 ab	0.1 ± 0.0 bc	725.0 ± 179.9 bcd	577.8 ± 170.5 de	63.0 ± 9.7 de	5.6 ± 1.2 bc	420.6 ± 81.1 ef
Batard	11 000.3 ± 1428.0 a	72.6 ± 11.6 d	71.6 ± 8.7 cd	−170.0 ± 85.2 ab	0.2 ± 0.1 a	2450.5 ± 840.8 a	1703.4 ± 441.4 a	199.8 ± 81.7 b	7.1 ± 0.8 ab	1342.7 ± 391.8 c
Big ebanga	9068.5 ± 1884.6 b	74.8 ± 21.2 d	75.2 ± 13.7 c	−171.1 ± 107.0 ab	0.2 ± 0.1 a	2098.4 ± 918.7 a	1499.3 ± 494.7 ab	423.8 ± 93.1 a	4.1 ± 0.2 c	2728.9 ± 1303.5 b
Kelong mekintu	7362.4 ± 535.0 c	103.4 ± 17.0 c	71.0 ± 10.9 cd	−566.1 ± 424.4 c	0.1 ± 0.0 bc	802.4 ± 171.4 bcd	539.6 ± 136.9 e	102.8 ± 16.2 c	6.9 ± 1.0 ab	687.5 ± 98.4 d
Average	6634.1 ± 1238.6	115.5 ± 24.2	73.4 ± 12.1	−364.3 ± 226.7	0.1 ± 0.0	1058.1 ± 352.5	816.6 ± 242.1	578.2 ± 34.3	5.3 ± 1.0	1222.7 ± 306.1

Abbreviation: NA, not available.

Table 8. Correlation between instrumental and sensory texture attributes.

	Correlation coefficient												
	Hardness-TPA (g)	Resilience (%)	Springiness (%)	Adhesiveness (g.s)	Cohesiveness	Gumminess	Chewiness	Hardness Penetrometry (g)	Distance at F_{max} (mm)	Area under curve (g.s)	Area under curve (g.mm)	S-Firmness	S-Humidity
Hardness-TPA (g)	1***												
Resilience (%)	−0.88***	1***											
Springiness (%)	−0.34 NS	0.43 NS	1***										
Adhesiveness (g.s)	0.30 NS	−0.17 NS	0.61 NS	1***									
Cohesiveness	0.84**	−0.69 NS	−0.05 NS	0.65 NS	1***								
Gumminess	0.93***	−0.76*	−0.20 NS	0.51 NS	0.97***	1***							
Chewiness	0.91***	−0.73*	0.00 NS	0.60 NS	0.96***	0.97***	1***						
Hardness-penetrometry (g)	0.63 NS	−0.54 NS	0.29 NS	0.50 NS	0.74*	0.68 NS	0.79*	1***					
Distance at F_{max} (mm)	−0.34 NS	0.53 NS	−0.15 NS	−0.18 NS	−0.40 NS	−0.31 NS	−0.42 NS	−0.77*	1***				
Area under curve (g.s)	0.50 NS	−0.41 NS	0.49 NS	0.47 NS	0.55 NS	0.50 NS	0.67 NS	0.94***	−0.74*	1***			
Area under curve (g.mm)	0.45 NS	−0.37 NS	0.52 NS	0.44 NS	0.48 NS	0.44 NS	0.61 NS	0.91***	−0.74*	1.00***	1***		
S-Firmness	0.53 NS	−0.74*	−0.77*	−0.32 NS	0.17 NS	0.31 NS	0.19 NS	−0.12 NS	−0.03 NS	−0.23 NS	−0.24 NS	1***	
S-Humidity	−0.87***	0.92***	0.63 NS	−0.09 NS	−0.64 NS	−0.76*	−0.66 NS	−0.27 NS	0.16 NS	−0.10 NS	−0.06 NS	−0.85**	1***

Note: NS, $P > 0.05$; *$P \leq 0.05$; **$P \leq 0.01$; ***$P < 0.001$.
Abbreviations: S-Firmness, sensory firmness; S-Humidity, sensory humidity.

consequently *Too humid or wet* could be a result of its inherent texture, which is related to its low dry matter content (Table 5). Studies by Ngoh Newilah *et al.*[17]on similar clones revealed that *CARBAP K74*, the least preferred variety by restaurant cooks, presented the least pulp firmness and dry matter contents. Qi *et al.*[29] confirmed that texture is the most important sensorial criterion for plantain consumers. However, considerably more consumers found *CARBAP 969* firmness just-about-right (see Supporting information, Fig. S1) compared to *CARBAP K74* (44.7% and 33.3%, respectively), although both genotypes had similar levels of dry matter content (Table 5). Out of all the genotypes, *PITA 21* presented the least dry matter content (Table 5), with the least firmness and overall quality (Table 6). These results suggest that this clone is not good for boiled plantain compared to *CARBAP 969*, *CARBAP K74*, *PITA 23* and *PITA 27*.

The sensory characteristics of boiled plantain loaded on the PCA plot confirms that good quality characteristics of boiled plantain include mainly smooth on sight, attractive, mealy, firm, good smell, plantain taste and yellow, whereas poor quality characteristics are denoted by terms such as taste of sap, pale color, moist, soft and odorless. These findings are in line with results obtained by Amah *et al.*[17] and Ngoh Newilah *et al.*,[18] respectively, in Nigeria and Cameroon, who mentioned softness, color, taste and odor as frequently mentioned attributes for boiled plantain pulps. Presently, plantain aroma remains undefined from laboratory analysis and measurement criteria. The physicochemical characteristics of the boiled plantain samples support landraces presenting a high dry matter content compared to bred hybrids. Similar results were obtained by Gibert *et al.*[30] and Ngoh Newilah *et al.*[3,18] on local plantain cultivars. The TSS and TTA are important post-harvest quality attributes because they are used primarily to estimate consumption quality and hidden attributes.[24] In addition, the assessment of acidity is important to evaluate the taste of the fruit.[24] No consistent pattern or trend in the sensory attributes of boiled plantain among the various genotypes was observed.

Firmness, humidity, sweetness and color were the sensory attributes scored by panelists during QDA, in addition to the overall acceptability. The high scores recorded for the attribute firmness (≥ 6) by *Batard*, *Kelong mekintu* and *PITA 23* compared to the low score (< 4) obtained by *PITA 21* could be attributed to the high DMC of the high-scoring clones compared to the low scoring ones. The latter also presented an (undesirably) high score for humidity. Landraces scored higher for color than bred hybrids probably as a result of their relatively high total carotenoid contents compared to bred hybrids.[28] However, the present study did not quantify carotenoids content and therefore could not confirm this. The high score for the attribute sweetness by the bred hybrid *CARBAP 969* means that sweetness is not correlated to TSS and TTA (Table S1) because this clone recorded values of 10°Brix and 511 meq per 100 g of malic acid. The overall acceptability scored by the panelists during QDA identified *PITA 21*, with a high score for humidity and the lowest score for color, as the least preferred clone. he PCA of the sensory attributes supports the results obtained from QDA, where the (high values) sensory attributes firmness and color were found to be more linked to the preferred landraces than the bred hybrids.

The indistinctive overlapping of concentric circles for each genotype in TPA than penetrometry suggests that the latter method is better at discriminating genotypes than the former. For TPA, hardness, gumminess, resilience and chewiness were the most discriminatory attributes. With penetrometry, hardness and area under the curve were the most discriminatory attributes. The clustering of the genotypes based on the protocols used can be used to classify the genotypes into three quality classes for consumer preference: good, intermediate and poor. This information can guide breeders in accessing the key priority traits that plantains can be bred for, aiming to improve adoption and consumer preferences.

CONCLUSIONS

The present study aimed at assessing the relationships that exist between texture and sensory characteristics of boiled plantain from nine accessions in Cameroon. Landraces were just-about-right for more than 45% of all the sensory attributes. *CARBAP 969* was the best among bred hybrids, (followed by *PITA 14*), showing an overall quality similar to those of the landraces. This is a promising finding and suggests that it should be possible to develop improved bred hybrids that combine resiliency, high productivity and consumer-preferred traits.

Out of the four QDA attributes, three were informative with a positive relationship with overall liking (firmness and color) or a negative one (humidity). Out of the four studied attributes for boiled plantain, color and firmness were the most important sensory characteristics because they were scored higher for landraces by the panelists. Significant correlations were observed between TPA and sensory texture, with negative correlations found between sensory humidity and hardness, sensory firmness and resilience, whereas a positive correlation was found between resilience and sensory humidity. However, although penetrometry discriminated genotypes better than TPA, it is not satisfactorily correlated with sensory texture. To resolve this non-correlation, a larger population of plantaingenotypes including bred hybrids and landraces should be analyzed. There is also a need to investigate plantain aroma based on laboratory analysis and measurement. There is a possibility of defining a target food profile of the attributes identified in the present study for boiled plantain. However, this will require a large sample size ($n \geq 20$ plantain clones) and a combination of parameters to obtain multilinear regression equations.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR CONTRIBUTIONS

GNN was responsible for conceptualization. CKV, ZD and OA were responsible for data curation. GNN and CKV were responsible for formal analysi. DD was responsible for funding acquisition. GNN, CKV, ATN, DFK, RNN, JTT, ENN, ZD, AB and DD were responsible for investigations. GNN, ZD, AB and DD were responsible for methodology. GNN was responsible for project administration. GNN was responsible for resources. GNN was responsible for supervision. CKV was responsible for writing the original draft. CKV, GNN, AB, ZD, OA, IG and DD were responsible for reviewing and editing.

ETHICS STATEMENT

The research described in this manuscript (from laboratory through consumer preferences interviews and surveys) has been previously and formally approved by the National Ethics Committee for Human Health Research in Cameroon. Written informed consent was obtained for all study participants.

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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