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Characterising quality traits of boiled yam: texture and taste for enhanced breeding efficiency and impact

Running title: Characterizing boiled yam for critical quality traits

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Abstract

BACKGROUND: Boiled yam key quality attributes typical for West African consumers are: crumbly, easy to break, and sweet taste. New yam varieties are being developed but high or medium throughput tools to assess the required quality traits and their range of acceptance are limited. This study assessed the acceptance thresholds of these quality attributes and established the predictive models for screening yam varieties that meet the required consumers' preferences.

RESULTS: Overall liking was associated with sweet taste, crumbly and easy to break (r values 0.502, 0.291 and -0.087, respectively). These parameters and selected biophysical parameters highly discriminated the boiled yam varieties. Crumbly texture and easy to break were well-predicted by penetration force and dry matter, whereas sweet taste by dry matter and sugar intensity. A high crumbliness and sweet taste are preferred (sensory scores above 6.19 and 6.22 for crumbly and sweet taste, respectively, on a 10 cm unstructured line scale), while a too high easiness to break is disliked (sensory scores ranging from 4.72 to 7.62). Desirable biophysical targets were between 5.1 and 7.1 N for penetration force, dry matter around 39% and sugar intensity below 3.62 g/100g. Some improved varieties fulfilled the acceptable thresholds, and the screening was improved through the deviation from optimum.

CONCLUSION: The acceptance thresholds and the deviation from optimum for boiled yam assessed through the instrumental measurements are promising tools for yam breeders.

Keywords: yam varieties; consumer acceptability threshold; sensory attributes; varietal adoption; selection index; high throughput phenotyping

INTRODUCTION

In West Africa, boiled yam may be either an end-product or an intermediate product in the pounded yam processing. Its simple preparation involves peeling, slicing and boiling.[1] All yam varieties can be boiled but not all of them exhibit the high-quality characteristics expected by consumers. Indeed, a deviation from the acceptable crumbliness, easiness to break, sweetness and white or yellowish colour (no discolouration) could lead to a rejection of a given variety.[1] Available information on these attributes is qualitative, essentially limited to consumer testing using a hedonic scale or Check-All-That-Apply (CATA) question,[1] thus, not convertible into measurable criteria that breeders could use. It was pointed out that users' varietal selections are influenced by their preferences for qualities associated with specific traits.[2]

To date, no study has generated validated relationships between sensory attributes and biophysical variables of boiled yam to be used by breeders to screen germplasm. The adoption of new varieties depends greatly on consumers' acceptance. All new varieties of dessert banana reported by Bugaud *et al.*[3] had been rejected because of either visual or sensorial flaws. Preferred varieties can be readily identified if the thresholds (acceptable range) of major quality traits are available. Additionally, appropriate high- or medium-throughput phenotyping protocols are required for timely and cost-effective screening of quality traits in breeding germplasm.[4] Unfortunately, there is limited information on thresholds of boiled yam quality attributes.

In food sciences, many relationships have been established to predict either intrinsic characteristics of food products or sensory attributes as a function of biochemical/biophysical characteristics.[5,6] The difference in paste firmness in yam has been related to the extent of cell disintegration, which was more pronounced for *Dioscorea alata*.[7] Dry matter of raw and boiled yams (DMR and DMB, respectively) are closely linked.[8] The physico-chemical measurements and starch functional properties do not fully explain the sensory perception of roots and tubers textural quality.[9] Reported correlations in yam were from studies that looked at an intermediate product for pounded yam processing,[10] instead of an end-product with a specifically targeted quality profile.

Understanding sensory attributes through robust and objective instrumental parameters with clearly defined thresholds is critical for efficient (rapid and early) screening of germplasm to ensure the adoption of new varieties. This study aimed to establish robust relations between sensory attributes and biophysical/instrumental variables and to determine the acceptance thresholds and the deviation from optimum for screening and selecting yam germplasm.

MATERIAL AND METHODS

Plant materials and locations

Plant materials (landraces and improved yam varieties) were obtained from Benin and Nigeria farmers' fields and research centres and were used in four experiments (Tables 1 and S1; Supporting information). TDa and TDr stand for improved clones of *D. alata* and *D. rotundata*, respectively. Landraces are composed of *D. alata* (Aga, Kpètè) and *D. rotundata* (Deba, Dodo, Gnidou, Irindou, Kpaïnan, Kodjèwé, Kratchi, Laboko, and Wété). Samples from Benin were grown at Dassa (7°45'N, 2°10'E) for Experiments 1 and 3. Materials from IITA-Nigeria (used for Experiment 2) were cultivated across two locations in Nigeria, namely Abuja (9°04'N, 7°29'E) and Ubiaja (7°30'N, 3°54'E), which differ in their agro-ecological conditions, such as rainfall patterns and temperature. The samples associated with each experiment and analysis are summarized in Table 1.

Experimental design

Samples preparation for sensory and biophysical analyses

Standard cooking procedures were employed to ensure consistency.[11] Yam tubers were sliced into three equal sections (proximal, middle, distal), and only the middle section was used in this study. After peeling, a punch was used to take cubic samples having 2.5 cm sides. The cubic samples (about 20 g per sample) were steam cooked for 38 min in 2 L of tap water in stainless steel saucepans using a gas cooker.

Quantitative descriptive analysis (QDA)

Three previously prioritized[1,12] sensory attributes including easy to break, crumbly and sweet taste (ST) were selected using triangulation tools according to the methodology reported by Forsythe *et al.*[13] These attributes were used for the quantitative descriptive sensory analysis, with 13 and 15 trained panellists for Experiments 1 and 3, respectively (Table 1). The panellists scored the randomly coded boiled yam samples for each sensory attribute on a 0-10 cm unstructured line scale using anchor descriptors for 0 (lowest intensity of attribute) and 10 cm (highest intensity of attributes). The samples were served at around 50 ± 2 °C, and the panellists immediately assessed the texture attributes for 2 to 3 min and, after that, the sweetness. Sensory evaluation took approximately 5 min per sample and was replicated three times.

Consumer testing

Samples were evaluated for Experiment 1 according to Honfozo *et al.*[1] Overall liking data were collected from 113 consumers, 18 to 70 years old, including 54.9% males. In addition, the 3-point "just about right" (JAR) test (1 = Too weak; 2 = "JAR: just about right" and 3 = Too strong) was performed on crumbliness, easiness to break and sweetness.

Dry matter

Dry matter content was determined in triplicate by oven drying fresh (DMR) and boiled (DMB) yam tubers according to Adesokan *et al*.[14]

Sugar contents

Soluble sugars were separated and measured, in duplicate, using HPLC according to Mestres.[15] The sugar intensity was calculated according to Schaafsma[16] as follows:

Saccharose + 0.6 x [Glucose] + 1.3 x [Fructose] + 0.5 x [Galactose].

Texture analyses

Penetration and double compression tests were performed according to Adinsi *et al.*[11] protocol using a texturometer (model TA-XT plus, Stable Micro Systems, Godalming, UK) on the samples collected in Benin from the same cooking batch used for quantitative descriptive analysis.

For the yam variety from IITA-Nigeria, the double compression test developed by Adinsi *et al.*[11] was slightly modified. Samples with regular shapes and sizes of 6 x 3 cm were analysed. A cylindrical compression probe of 35 mm was used at a test speed of 1.2 m/s and a load of 10 g. For each test, six replications were performed per sample.

Ethical assessment and consent for sensory evaluation and consumer testing

The research described in this manuscript was previously and formally approved in Benin by the "Comité National d'Ethique pour la Recherche en Santé" under approval number 16 of 6th may 2020. Written informed consent was obtained for all study participants.

Statistical analysis

Sensory (QDA and overall liking) and biophysical data were subjected to the analysis of variance (ANOVA) followed by the least significant difference (LSD)-Fisher post-hoc test. JAR test data were analysed by counting the percentage of respondents who evaluated each boiled yam sample as JAR 'just about right'. Linear (simple and multiple) and Partial Least Squares (PLS) regressions were applied to predict the sensory attributes and overall liking by the biophysical parameters. For models of sensory attributes, the number of variables was reasonably set to a maximum of two to minimize the laboratory analyses involved. In this case, a high coefficient of determination (R^2) between predicted and observed variables and the lowest Root Mean Square Error of Calibration (RMSEC) were considered to assess the quality of the model. The robustness of the model validation was evaluated by the Root Mean Square

Error of Validation (RMSEV). Regarding the overall liking, the best model was selected by using the lack of fit test (F-test) and associated p-value. All analyses were performed using XLSTAT (version 2016.02.28451, Addinsoft, Paris, France).

The thresholds of sensory attributes and their equivalent biophysical parameters were computed by linking the intensity of sensory attributes and biophysical parameters to their "satisfied" level of JAR, according to the methodology developed by Bugaud *et al.*[3] but slightly modified as follows: the percentage of consumers who judged boiled yam to be JAR (2 on the scale) was linked to the intensity scored in QDA, and the relationship was fitted with a linear/quadratic function. The score of attributes at which the percentage of consumers who judged the boiled yam to be JAR was above 80% or 60% was assessed to stand for optimal and acceptable levels, respectively. The threshold of 80% of satisfied consumers was chosen because an attribute is considered optimal according to the Pareto principle.[17] The threshold of 60% of satisfied consumers (20% decrease from optimal level) was chosen as the acceptable threshold. Based on the score (optimal and acceptable) of sensory attributes determined, the optimal/ideal and acceptable levels of explicative biophysical parameters were assessed using predictive models from multiple regressions.

To screen and rank yam varieties, the selection index described by León *et al.*[18] was modified as follows: on the scale of overall liking (OL), the deviation from the ideal/optimum (DI_{OL}(obs→opt)) was determined for each variety and used as selection index. It was calculated using the regression coefficient (β) between consumers' overall liking and relating parameters. Accordingly, the deviation ($Value_{observed}$ - $Threshold_{optimal}$) of each parameter from the optimal thresholds target was standardized and DI_{OL} was calculated as follows:

$$DI_{OL} = \sum_{i=1}^{n} \left(\beta_i \times \left(Value_{observed_i} - Threshold_{optimal_i} \right) \right)$$

where "i" stands for each relevant parameter in the predictive models explaining consumers' overall liking.

RESULTS

Quality attributes and biophysical characteristics of boiled yam as affected by variety and harvesting location

Tables 2 and 3 present the mean values of overall liking, sensory attributes and biophysical parameters of boiled yam with varietal (Experiment 1) and harvesting location (Experiment 2) effects, respectively. For all sensory attributes, the range of variation of the scores was very large (> 3.0) on the 0-10 cm unstructured linear scale. There were significant differences between yam varieties for the mean scores of crumbliness, easiness to break, and sweetness (Table 2). *D. alata* genotypes (TDa 1520002, TDa 1520050 and Aga) generally showed the highest scores (> 7) for crumbliness and easiness to break compared with *D. rotundata* clones, but had lower ST (< 5 vs. > 6). Laboko had a high crumbliness (7.2) for a *D. rotundata* but median easiness to break score (5.9). The varieties' overall liking varied significantly (Table 2). Laboko was the most preferred variety, while Aga and Irindou were the least.

Regarding sugars, saccharose (96.2%), glucose (2.4%), fructose (0.9%) and galactose (0.5%) were identified in the raw yam. The sugar intensity of raw yam, expressed as saccharose equivalent, varied from 2.8 g/100g in Irindou to 5.1 g/100g for Dodo (Table 2). Boiling decreased DM (Table 2) by 0.4% for TDa 1520050 to 4.5% for Wété.

The mean penetration (PF, 4.9–9.7 N) and compression (CF, 28.5–84.7 N) forces measured on boiled yam, and the DMR, exhibited significant varietal and harvesting location effects (Tables 2 and 3). For instance, CF was always significantly lower in Abuja than in Ubiaja (Table 3). The averages for CF (across the two locations) varied from 14.3 for TDa 1508044 to 30.3 N for TDa 1515030. The range of DMR from Ubiaja (25.5–39.5%) was wide compared to samples from Abuja (26.7–34.2%) in Nigeria (Table 3).

Comprehensive relationships within and between sensory attributes and biophysical characteristics of boiled yam

The crumbly texture was positively and significantly correlated with easy to break but negatively to ST. A significant and positive correlation was found between PF and CF (Table 4). The linear regression equation was PF = 0.07*CF + 2.62 ($R^2 = 0.88$). Both were negatively and significantly correlated to the sensory texture attributes. Although some correlations between overall liking and any sensory attributes or instrumental texture parameters were relatively high, none reached statistical significance (Table 4). A positive and significant correlation was found between DMR and DMB (Table 4). Moreover, the easiness to break was significantly and negatively correlated with DMR and DMB. Correlations between the two dry matter and the penetration and compression forces were relatively high, but non-significant (Table 4). Furthermore, a negative but not significant correlation was observed between the sugar intensity of raw yam and the sweetness of boiled yam (Table 4) while an unexpected negative correlation was found between ST and crumbly.

Prediction of sensory attributes and overall liking of boiled yam through biophysical parameters

Sensory attributes

Multiple linear regression analyses (Experiment 1) revealed that crumbliness was properly predicted by the PF alone ($R^2 = 0.88$; RMSEC = 0.34), while easiness to break required both PF and DMR ($R^2 = 0.95$; RMSEC = 0.31; Table 5). The prediction models were validated by new independent samples (Experiment 3; Table S2). The robustness of the prediction was sufficient ($R^2 \geq 0.79$; $0.85 < \text{RMSEV} < 1.46$) to score both attributes with a bias less than 1.25 points on the 0–10 cm unstructured linear scale (Table 5). Regarding ST, it was predicted (Table 5) by raw yam's sugar intensity and DMR ($R^2 = 0.73$, RMSEC = 0.34).

Overall liking

The overall liking of boiled yam was predicted (Table 5) by multiple regression analysis from PF and DMR (R^2 = 0.79, lack of Fit = 8.11, $P < 0.05$, Table S3) (Experiment 1). However, based on R^2 value (0.88) a model with three parameters (DMR + PF + ST) can also be used even if the lack of fit test was not significant (Table S3). The overall liking, for seven yam varieties grown in Nigeria (Table 3) were determined using the predicted PF and DMR from Experiment 2. Irrespective of harvesting location, the overall liking varied from 5.2 (like slightly) to 7.1 (like much).

Thresholds for acceptance of key attributes of boiled yam

Texture

The thresholds of sensory attributes and their corresponding biophysical parameters were evaluated considering 60% (acceptable) and 80% (optimal) JAR levels (Experiment 1). For the crumbliness and the easiness to break, R^2 values ranged between 0.62 and 0.88, showing a strong relationship between sensory and biophysical variables (Table S4, Supporting information). Based on the sensory analysis (0–10 scale), the optimal texture of boiled yam was scored between 5 and 7 for the easiness to break and above 7 for the crumbliness (Table 6). Concerning the easiness to break, the corresponding optimal thresholds of PF ranged between 6 and 8 N, concomitant to the DMR content between 35 and 38%, while PF below 6 N characterised the optimal crumbliness (Table 6). Thus, based on the thresholds of PF, no variety can have an optimal crumbliness and easiness to break texture simultaneously (the maximum threshold for crumbliness is below the minimum threshold for easiness to break). However, some varieties (Laboko, TDa 1520050 and TDa 1520002) were close to the optimal threshold characteristics.

The acceptable texture (60% JAR) was characterised by scores between 5 and 8 for the easiness to break and above 6 for the crumbliness. Acceptable (60% JAR) easiness to break was characterised by PF between 5 and 9 N and the DMR between 33 and 40%. At the same time, the crumbliness was judged acceptable if the PF was below 7 N.

Sweet taste

The optimal sweetness (80% JAR) of boiled yam was characterised by a sensory score of ST above 7, corresponding to the sugar intensity of raw yam below 3 g/100g and the DMR above 45% (Table 6). In contrast, the acceptable sweetness of boiled yam (60% JAR) was associated with a sensory score above 6, a sugar intensity of raw yam below 4 g/100g and a DMR around 39% (Table 6).

Screening of yam varieties using texture acceptability thresholds

The seven varieties grown in Abuja and Ubiaja were screened based on the calculated acceptable thresholds (Table 6). Regardless of the harvesting location, the sensory scores of the crumbliness and easiness to break (predicted using the regression equations presented in Table 5) were high (ranging between 6.1 and 9.4 on the 0-10 scale), while the predicted PF were low (3.1–6.6 N) (Table 3). Based on the sensory scores, no variety from either area had the textural characteristics of optimal boiled yam, *i.e.* when crumbliness and easiness to break were simultaneously considered at their optimal level (80% of satisfied consumers). However, TDa 1510043 and TDa 1515030 grown in Ubiaja, met the requirements from the acceptable threshold (60% of satisfied consumers). Furthermore, based on biophysical variables, only TDa 1510043 and TDa 1515030 grown at Ubiaja can be considered easy to break because they matched for DMR (Table 3) at acceptable level and PF at optimal level. Regarding crumbliness, all varieties can be considered crumbly at acceptable levels. Indeed, except TDa 1510043 and TDa 1515030 grown at Ubiaja that matched for PF at an acceptable level, the other samples matched at the optimal level. Similar to the sensory acceptability threshold, the screening from the biophysical variables' threshold revealed that the crumbly and easy to break samples were TDa 1510043 and TDa 1515030 grown in Ubiaja.

Use of selection index to identify promising varieties based on biophysical parameters

As previously established, the DMR and PF explained the overall liking of consumers, while the PF was predicted from CF (Table 3) (PF = 0.07*CF + 2.62; R2 = 0.88). The samples harvested in Abuja and Ubiaja areas were screened based on the deviation (DI) from the ideal/optimum on the overall liking scale (Table 3), used as selection index. Regardless of the harvesting location, DI ranged from -0.58 to 0.49. Variety x location samples with high DI values were corresponded to those with high overall acceptance. DI ranked all yam varieties grown at Abuja among the top seven. In each location, TDa 1508044 was assigned the first rank.

Mapping of sensory attributes, biophysical parameters and yam genotypes

The PLS regression (Fig. 1) performed on data collected in Experiment 1 (Tables 2 and 3) confirmed that PF or CF explained the texture attributes (easy to break and crumbly), while the ST was strongly associated with DMR and DMB. The overall liking was highly and positively correlated to DMR and DMB but weakly and negatively to sugar intensity. The PLS also revealed, to a large extent, that the yam varieties were grouped into two classes with respect to species. Indeed, while 87.5% of samples from *D. alata* genotypes were in the left, varieties of *D. rotundata* were in the right. Furthermore, the *D. alata* TDa 1510043 and TDa 1515030 clones grown at Ubiaja were close to the acceptance threshold in texture attributes and related biophysical parameters. Both clones were the only *D. alata* located close to the *D. rotundata* varieties.

DISCUSSION

The PF and DMR tightly explained the overall liking of boiled yam. These results show for the first time that the acceptability thresholds for boiled yam have been determined and used for yam genotypes screening. However, the values calculated for the thresholds present two situations. Firstly, for the optimal product (80% of satisfied consumers), the ranges obtained for some biophysical parameters exclude each other, thus making impossible the simultaneous satisfaction of the relevant traits. This is the case of PF associated with a crumbly texture and easy to break or DMR related to ST and easy to break. Secondly, at 60% of satisfied consumers, most thresholds widen, and therefore expand the range of parameter variation. As a result, the number of yam varieties that pass through the screening is high. As a solution, the use of DI is promising and helpful to select and rank yam varieties that are close to optimal levels of overall liking simultaneously across a set of relevant traits. Consequently, the DI is highly appropriate to screen yam varieties. The effect of harvest locations observed on the DI demonstrates that it is sensitive, as it should, to growing environmental conditions. Several selection tools are generally used by breeders to allow ranking of top varieties.[18] The use of the deviation of preferred variables from the optimum as well as the regression coefficients as weights in our study should give consistent results.

The correlations between instrumental parameters (biophysical, biochemical) and sensory attributes have been the subject of several publications[3,5,6,8] but, the profile of the ideal/optimal product[8] as well as the acceptability thresholds[3] have been poorly documented. Several studies[5,6] have provided evidence that sensory attributes' scores varied within and between genotypes, and specifically for yam, some variation between samples is expected, in agreement with Mestres *et al.*[19], who reported a sizeable sensory score range covering the whole scale.

D. alata clones have generally lower scores of crumbliness, easiness to break and ST compared to *D. rotundata*.[1] The panellists had some difficulty to correctly assess crumbliness, especially when the samples are very easy to break. Likewise, the sweetness was difficult to score discriminately due to the narrow range of sugar in samples. Thus, the negative association observed between crumbliness and ST (Table 4) should be considered with caution. van Oirschot *et al.*[9] reported from sweet potato that crumbliness is a complex organoleptic sensation which is difficult to assess. It is generally accepted that crumbliness is due to cell rupture on chewing, and crumbly varieties display more "cell disorganisation" than non-crumbly ones.[20] Therefore, the higher the instrumental cohesive force between cells, the lower the cell disintegration[20] and the lower the crumbliness. This fact could be confirmed by the negative significant correlation between a crumbly sensory attribute and PF and CF. Favaro *et al.*[21] linked the low hardness of cooked roots and tubers to the separation of intact cells rather than the rupture due to the disintegration of middle lamellae (cells "round off" during boiling) to become easily separable. The methods used for the penetration and compression tests could lead to the rupture of samples since they reflected more the technique used by the panellists to assess easiness to break, thus they could be linked more to the easiness to break than to the crumbliness. Furthermore, the texture parameters depend on DM which varied between locations, which in turn are influenced by the soil carbon content,[22] or/and the amount of rainfall received over the tubers growing phases, among other possible differences.[23] DM effect on texture was also highlighted by Gibert *et al.*[24] who reported a positive correlation between the DM of raw banana and the hardness of boiled banana while Hongbété *et al*.[23] reported a negative correlation for cassava. Consequently, the role of starch, as the main component of roots and tubers, is complex and variable in textural behaviour of the end-products, thus in PF and CF measured. Given that the crumbly samples were also easy to break their prediction by PF could be due to co-linearity between these sensory traits, as reported by Kouassi *et al.*[6] for boiled plantain.

Sugar content should be another criterion for yam breeders for phenotyping. However, the relationship between sugar intensity and ST of boiled yam is negligible, in agreement with Laurie *et al.*[25] for sweet potato. This is probably due to the observed narrow range in sugar content and the presence of bitter molecules such as polyphenols, which could mask the ST and lead to wrong and incoherent detection of sweetness differences in the mouth by assessors. Kouassi *et al.*[6] reported that an increase in the soluble solid content of 4°Brix was sufficient for the panellists to perceive a significant and coherent difference. This led to a 2-point increase in the sweetness of boiled plantain. Mestres *et al.*[19] reported antagonistic roles of sweet and bitter molecules such as phenol and proanthocyanin in the paste from yam chips flour expressed by positive and negative correlations with bitterness and sweetness, respectively. Furthermore, during cooking, starch degradation occurred and allowed an increase in sugars, as pointed out by Chan *et al.*[26], who observed that maltose formed during baking of sweet potato contributed to the final sweet sensation of the cooked root. This phenomenon of starch saccharification can be suspected in our study, given the sugar content and the scores obtained by some varieties. Accordingly, the ST of boiled yam should be interpreted with caution or through other deepened mechanisms/models. Bugaud *et al.*[27] reported that the sweetness of dessert banana was predicted to a lesser extent by saccharose, confirming that other biophysical parameters play a prominent role in predicting ST.

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CONFLICT OF INTEREST

None

SUPPORTING INFORMATION

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

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Figure Caption:

Figure 1. PLS regression showing the sensory attributes (X) and the biophysical parameters (Y) (left) and yam genotypes (right).

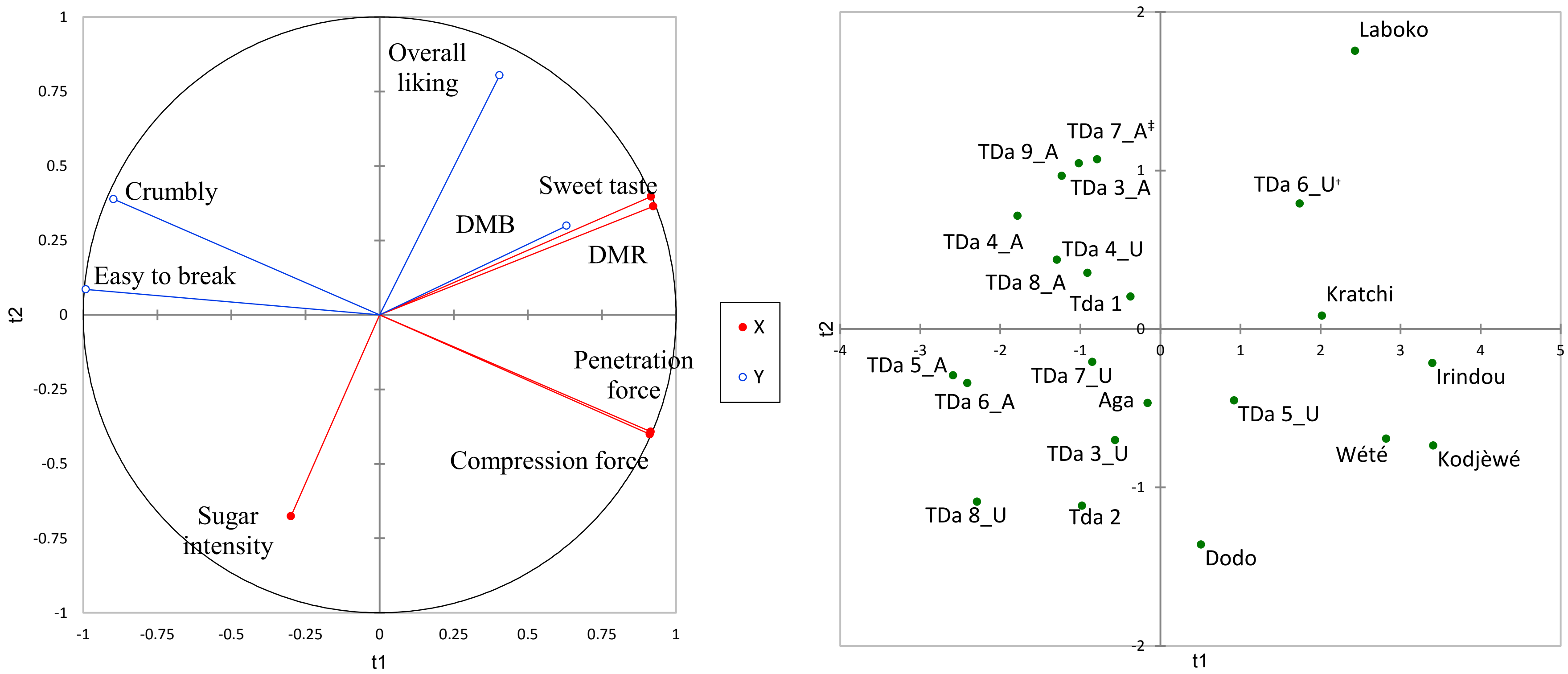

Figure 1. PLS regression showing the sensory attributes (X) and the biophysical parameters (Y) (left) and yam genotypes (right).

†U: Ubiaja; ‡A: Abudja; DMR: Dry matter of raw yam; DMB: Dry matter of boiled yam

Table 1. Yam varieties tested for each experiment and analyses methods used

Origin	Yam varieties	Experiment	Analyses	Prediction of models	Validation of models	Predicted parameters
Farmer fields- and AfricaYam-Benin	Aga[†‡], Dodo[†‡], Irindou[†‡], Kodjèwé[‡], Kratchi[†‡], Laboko[†‡], Wété[†‡], TDa1, TDa2	1	QDA (crumbly, easy to break, sweet taste), penetration and compression tests, DMB and DMR, sugar intensity[†], JAR test[‡], and overall liking[‡]	Crumbly and easy to break, sweet taste[†] and overall liking[‡]		
	Kodjèwé, Gnidou, Deba, Kpètè,	3	QDA (crumbly, easy to break, sweet taste), penetration test, DMR and sugary intensity		Crumbly, easy to break and sweet taste	
IITA-Nigeria	TDa3, TDa4, TDa5, TDa6, TDa7, TDa8, TDa9	2	DMR, compression force,			Penetration force, crumbly, "easy to break", overall liking

[†] and [‡] stand for specific analyses performed on some samples; na: not applicable; DMR: Dry matter of raw yam; DMB: Dry matter of boiled yam; QDA: Quantitative descriptive analysis; JAR: Just-About-Right test

Table 2. Mean values of overall liking, sensory attributes and biophysical parameters of raw and derived boiled yam (Experiment 1)

Variety type	Samples name	Overall liking score (1 to 9 scale)	Sensory attribute scores_boiled (0-10 cm scale)			Hardness_boiled (N)		Sugar intensity_raw (g/100g, dry solid, SE†)	Dry matter (g/100, wet solid)	
			Crumbly	Easy to break	Sweet taste	Penetration	Compression		Raw	Boiled
Landrace	Dodo	6.0^{bc}	6.4^{abcd}	7.3^{a}	6.3^{ab}	6.8^{c}	58.4^{b}	5.1	32.9^{b}	30.0^{d}
	Kratchi	6.6^{b}	5.9^{bcd}	5.8^{b}	6.2^{ab}	6.8^{c}	64.0^{b}	3.7	38.8^{a}	34.8^{c}
	Irindou	5.6^{c}	5.7^{cde}	4.6^{cd}	6.1^{abc}	8.5^{b}	84.7^{a}	2.8	39.9^{a}	37.0^{b}
	Kodjèwé	6.2^{bc}	4.5^{e}	4.4^{d}	6.8^{a}	9.7^{a}	79.7^{a}	nd	39.9^{a}	36.0^{bc}
	Wété	6.4^{b}	5.3^{de}	4.6^{cd}	6.1^{abc}	8.1^{b}	81.6^{a}	4.5	39.7^{a}	35.2^{bc}
	Laboko	8.0^{a}	7.2^{ab}	5.9^{bc}	6.7^{a}	6.0^{cde}	45.6^{c}	3.1	42.1^{a}	39.4^{a}
	Aga	5.7^{c}	7.1^{abc}	7.5^{a}	4.6^{cd}	5.8^{de}	39.4^{cd}	3.8	31.4^{bc}	30.4^{d}
Improved	TDa 1520050	nd	7.1^{abc}	7.8^{a}	4.8^{bcd}	4.9^{e}	28.5^{d}	nd	30.3^{c}	29.9^{d}
	TDa 1520002	nd	7.8^{a}	7.8^{a}	3.7^{d}	5.3^{e}	42.0^{cd}	nd	28.3^{c}	27.4^{d}

†SE: Saccharose equivalent; nd: not determined

Mean values with different superscript letters in the same column are significantly different ($p<0.001$).

Table 3. Key biophysical parameters and deviation from ideal of yam samples as affected by harvest location (Experiment 2)

Varieties	**Location**	**DMR (g/100g, wet solid)**	**Compression force (N)**	**†Predicted**				**DI**	**Rank**
				Penetration force (N)	**Crumbliness (score)**	**Easiness to break (score)**	**Overall liking (score)**		
TDa 0000194	Abuja	34.2^{a}	13.9^{b}	3.7	8.3	8.2	7.1	0.40	4
	Ubiaja	30.5^{b}	39.0^{a}	5.5	7.2	7.8	5.6	-0.35	12
TDa 1508044	Abuja	31.0^{a}	6.7^{b}	3.1	8.7	9.0	6.7	0.49	1
	Ubiaja	32.2^{a}	22.0^{a}	4.2	8.0	8.2	6.5	0.15	8
TDa 1510043	Abuja	26.7^{a}	9.4^{b}	3.3	8.5	9.5	5.8	0.27	5
	Ubiaja	34.6^{a}	54.0^{a}	6.6	6.5	6.6	5.9	-0.58	13
TDa 1515030	Abuja	27.0^{b}	12.2^{b}	3.5	8.4	9.4	5.8	0.21	7
	Ubiaja	39.5^{a}	48.5^{a}	6.2	6.8	6.1	7.0	-0.27	11
TDa 1520008	Abuja	33.6^{a}	11.7^{b}	3.5	8.4	8.4	7.0	0.45	3
	Ubiaja	31.0^{b}	29.3^{a}	4.8	7.6	8.1	6.0	-0.10	9
TDa 1520050	Abuja	31.5^{a}	16.1^{b}	3.8	8.2	8.5	6.5	0.27	5
	Ubiaja	25.5^{b}	22.9^{a}	4.3	7.9	9.2	5.2	-0.12	10
TDa 1520002	Abuja	32.9^{a}	9.8^{b}	3.4	8.5	8.6	6.9	0.46	2
	Ubiaja	35.3^{a}	nd	nd	nd	nd	nd	nd	nd

†Predicted using prediction regression equations; DMR: Dry matter of raw yam; DI: Deviation from ideal/optimum

Mean values with different superscript letters within the same column for a specific sample are significantly different ($p<0.05$).

nd: not determined

Table 4. Pearson correlation between sensory attributes, overall liking and biophysical data from Experiment 1

Variables	Overall liking	Crumbly	Easy to break	Sweet taste	Penetration force	Compression force	DMR	DMB	Sugar intensity_raw
Overall liking	**1**								
Crumbliness	0.291	**1**							
Easiness to break	-0.087	**0.854**[†]	**1**						
Sweet taste	0.502	**-0.721**	**-0.754**	**1**					
Penetration force	-0.338	**-0.939**	**-0.893**	**0.694**	**1**				
Compression force	-0.328	**-0.874**	**-0.899**	0.658	**0.936**	**1**			
DMR	0.593	-0.639	**-0.852**	**0.862**	0.606	0.607	**1**		
DMB	0.631	-0.522	**-0.817**	**0.805**	0.563	0.558	**0.953**	**1**	
Sugar intensity_raw	-0.226	-0.151	0.443	-0.061	-0.086	-0.053	-0.567	-0.765	1

DMR: Dry matter of raw yam; DMB: Dry matter of boiled yam; [†]Numbers (>0.694) in bold represent significant correlation (P<0.05);

Table 5. Multiple linear regressions between biophysical parameters, overall liking and sensory attributes

		Calibration§		Validation		
Dependent variables	**Prediction regression equation**	**R^2**	**RMSEC**	**R^2**	**RMSEV**	**Bias**
Crumbliness = f (Lab)†	- 0.61 x Penetration force (N) + 10.56	0.88	0.34	0.79	0.85	-0.72
Easiness to break = f (Lab)	15.33 – 0.54 x Penetration force (N) – 0.15 x DMR (g/100g)	0.95	0.31	0.88	1.46	1.21
Sweet taste = f (Lab)	-2.4 + 0.18 x DMR (g/100g) + 0.43 x Sugar intensity (g/100g)	0.73	0.34	nd	nd	nd
Overall liking = f (Lab)	2.4 – 0.41 x Penetration force (N) + 0.18 x DMR (g/100g)	0.79	0.38	nd	nd	nd

§Calibration performed with data from experiment 1 †Model validated with data from experiment 3; nd: not determined; DMR: Dry matter of raw yam

Table 6. Acceptability thresholds for sensory attributes and biophysical parameters of raw and boiled yam

Sensory attributes	JAR level (%)	Sensory score		Penetration force (N)		Sugar intensity_raw (g/100g, dry basis)	DMR (g/100g_oven)	
		Min	Max	Min	Max		Min	Max
Easy to break†	60	5 (4.72) §	8 (7.62)	5 (5.1)	9 (8.6)	nd	33 (33.2)	40 (39.6)
	80	5 (5.29)	7 (7.04)	6 (5.8)	8 (7.9)	nd	35 (34.5)	38 (38.4)
Crumbly‡	60	> 6 (6.19)		< 7 (7.1)		nd		
	80	> 7 (7.03)		< 6 (5.7)		nd		
Sweet taste‡	60	> 6 (6.22)		nd		< 4 (3.62)		> 39 (39.2)
	80	> 7 (6.96)		nd		< 3 (2.97)		> 45 (44.9)

†Quadratic function; ‡Linear function; nd: not determined; DMR: Dry matter of raw yam;

§In brackets, the observed threshold and out brackets, the rounded value of threshold