Research Article

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End-user preferences to enhance prospects for varietal acceptance and adoption in potato breeding in Uganda

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Abstract

BACKGROUND: Potato varieties have diverse biophysical characteristics, so it is important for breeders to have the capacity to choose those that meet the preferences of end users, such as mealiness, firmness, and taste, among others. Combining user preferences with descriptive information regarding the sensory characteristics of boiled potatoes can contribute to the improvement of consumer-driven varieties. This study aimed to factor in the preferences of end users to improve the prospects for varietal acceptance, adoption, and discrimination among genotypes in potato breeding.

RESULTS: The priority quality traits (traits that play the most significant roles in acceptance and adoption) of the boiled potatoes were determined by evaluating gender and livelihood using the G+ tool. The G+ tool is designed to assess gender impact on roots, tubers and bananas (RTB) traits by serving as a validation check to reflect on important gender-based issues in agricultural food systems in order to reduce harm and promote positive impact. Potato genotypes were differentiated by penetration (textural parameters as measured by standard texture probe) and the procedure was repeatable, as there was no significant difference between the cooking replicates at 40 min of cooking. Instrument-based texture parameters, such as penetration peak force (hardness/firmness) and area (area under the curve, which represents energy needed to penetrate) of boiled potato tubers were significantly associated with sensory attributes such as fracturability and hardness in the mouth. An attempt to differentiate genotypes using near-infrared spectroscopy (NIRS) revealed that the average results observed for the calibration for yellow color ($r^2 = 0.70$), homogeneity of color ($r^2 = 0.48$), moisture in mass ($r^2 = 0.40$), and uniformity of texture ($r^2 = 0.56$) suggested that these parameters could be used for initial breeding screening purposes.

CONCLUSIONS: The preferred traits of the boiled potato can be integrated into the potato-breeding program/product profile. Near-infrared spectroscopy shows strong potential to predict potato color and the ability of NIRS models to predict some texture attributes is also promising.

Keywords: NIRS; texture; gender; product profile; *Solanum tuberosum*

INTRODUCTION

Potato (*Solanum tuberosum*) is an important crop in many regions of the world and a staple food in many diets. In Africa, it provides an excellent source of income for smallholder farmers and plays an important role in food security.[1] The tubers can be boiled, mashed, baked, fried, roasted, or steamed, and their high starch content makes them a versatile ingredient for many dishes. Potato varieties can vary in texture depending on their starch and sugar composition. As these variations influence the preference of consumers for potato genotypes,[2] it is important for breeders to consider them and to select the genotypes that meet the preferences of end users.

Crop breeding has been very successful, especially with regard to gains in superior agronomic traits. However, in public breeding programs in developing countries, new varieties have not reached their full potential because of suboptimum attention

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given to traits preferred by consumers. As such, targeted breeding for end-user preference has been proposed to address this challenge.[3,4] Furthermore, promoting potato varieties without considering the needs of disadvantaged social groups, such as women and youth, who are typically the target beneficiaries of public breeding programs, may reduce acceptance and adoption rates. For example, one of the persistent disparities between male and female farmers is the lower adoption of modern varieties by households with female heads than by households with male head.[5] Women in male-headed households, on the other hand may have access to modern varieties derived from breeding technologies but not the ability to utilize them due to gender-based access to the varieties.[6]

To screen large populations of potato genotypes for advanced breeding and consumer acceptance, a medium-throughput procedure such as instrument-based texture measurement may be needed to distinguish genotypes based on their textural properties.[7] This is especially true because most breeding programs in sub-Saharan Africa rarely consider the role of texture of potato food products as a key driver of adoption and consumption of new varieties. The expensive and time-consuming process of conducting sensory tests to assess genotypes can also be improved by using simple instrument-based texture assessment procedures to predict sensory acceptance of potato products such as boiled potato.

Instrument-based texture profile analysis (TPA) and spectroscopic methods have been examined for the prediction of sensory traits in potatoes, especially in the Global North. Here, significant correlations have been detected between sensory traits and instrumental methods – for example instrumental hardness was negatively correlated with mealiness in cooked potatoes.[8] In fried potatoes, positive correlations between instrumental fracture force and sensory textural attributes such as hardness, crunchiness, and chewiness, were high and significant ($r^2 = 0.76–0.96$).[9] More important, high-throughput techniques such as near-infrared spectroscopy (NIRS) are appropriate because of their ability to phenotype many traits in a short time and at lower cost. Near-infrared spectroscopy is a nondestructive tool that can increase rapidly the speed at which quality traits are evaluated. It has been used to assess a wide range of crop traits, including sensory traits and phytochemical variability and to predict nutrient levels in the tubers.[10-12] In potatoes, NIRS has predicted sensory texture attributes such as moistness, waxiness, firmness, and mealiness with correlation coefficients between 0.68 and 0.94.[13,14] However, in sub-Saharan Africa, the current literature on cooked potato provides little information regarding the power of instrument-based texture analysis and NIRS to differentiate among potato genotypes for consumer acceptability. Among the key texture attributes for cooked potato, sensory firmness and mealiness have been found to influence consumer perception significantly.[15,16]

The current study aims to explore end user preferences to improve the prospects of acceptance and adoption of released potato varieties. It focuses on: (i) understanding gender considerations for customer targeting and trait prioritization in variety development, and (ii) instrument-based measurement of firmness of potatoes and assessing how it is correlated with sensorially perceived textural attributes of boiled potato. (iii) The study also assesses whether NIRS can be used as a high-throughput tool to predict the sensorially perceived textural attributes.

MATERIALS AND METHODS

Gender analysis using a G+ tool to identify targeted traits

The initial study was carried out in Rakai and Kabale districts in western Uganda, where potato is an important crop with the potential to contribute significantly to increasing rural income and the improvement of food and nutrition security.[17] Most potatoes are consumed in boiled form, although there is a growing demand for processed potato products such as French fries.[17] In Uganda, annual potato production is estimated at 246, 393 metric tons in 2021 (FAOSTAT 2023, www.fao.org/faostat/en/#data/QCL).

The study considered the triangulation of the most preferred raw, processed, and final product quality characteristics for boiled potatoes. It was carried out using a four-stage stepwise process that included (i) an assessment of the state of knowledge; (ii) gendered food mapping; (iii) participation process diagnosis; (iv) consumer testing,[11] and (v) review and finalization of the

Table 1. Potato genotype panel used for the instrument-based and sensory evaluations of the texture of boiled potato

No.	Genotype	Type	Skin color	Flesh color	Tuber shape
1	CIP312084.731	Breeding line	Yellow	Yellow	Long oval
2	CIP312010.759	Breeding line	Yellow	Cream	Oval round
3	CIP313001.649	Breeding line	Red	Yellow	Long oval
4	CIP313011.028	Breeding line	Red	Yellow	Oval
5	CIP314909.279	Breeding line	Red	Cream	Round oval
6	CIP314909.002	Breeding line	Yellow	Cream	round
7	CIP314909.044	Breeding line	Yellow	Cream	Oval
8	CIP314910.019	Breeding line	Yellow	Cream	Round
9	CIP314915.069	Breeding line	Yellow	Yellow	Round
10	CIP314926.026	Breeding line	Red	Cream	Long oval
11	CIP314938.014	Breeding line	Purple	Yellow	Round oval
12	CIP314909.060	Breeding line	Yellow	Cream	Round
13	Dutch	Local variety	Red	Yellow	Round
14	Shangi	Local variety	Red	Yellow	Oval
15	Unica	Local variety	Red	Yellow	Long oval
16	Wanjiku	Local variety	Yellow	Cream	Oval

gendered product profile.[18] The results of steps (i) to (iv) are reported in Mudege *et al*.[16] To finalize the gendered product profile (step v), four sub-steps were undertaken. These included (i) preparation of an evidence and summary table; (ii) review of the evidence and summary table by a 'multidisciplinary' design team; (iii) application of the adapted G + tool, and (iv) finalization of the gendered product profile for boiled potato.[18] The adapted versions of the gender and livelihood assessment tool, the G+ Product Profile tool, and the accompanying G+ Product Profile Query tool[19] were used at this stage. The tools allow for a deeper understanding of the potential impact of profiled characteristics on women and men.

Using the G+ Product Profile tool, the profiled characteristics were prioritized and analyzed for gender impact with the help of the 'Positive benefit' and 'Do no harm' scales. Under positive benefit, the characteristics were scored as 0 = neutral (no significant benefit), +1 = nice to have (moderate benefit), +2 = required (considerable benefit). For the 'Do no harm scales', 0 = neutral (no significant harm), −1 = amend or avoid (moderate harm), and −2 = reject (considerable harm). The G+ Product Profile tool was applied in two stages within a workshop setting. First, multidisciplinary participants (comprising breeders, biochemists, food scientists, and agronomists) analyzed the profiled characteristics individually, based on expert opinion, and recorded the results on tablets. Then the collated results were discussed in plenary and a consensus score was obtained. This score was used to decide on the final priority traits to recommend for inclusion in the product profile.[20] The evaluation provided a foundation and focus for breeders, biochemists, and food scientists to understand these characteristics better and holistically.

Table 2. Summary of prioritized characteristics after four-stage triangulation

Raw potato	Processing	Boiled potato
Red skin and yellow flesh color	Easy to peel	Moderately firm (neither too soft nor too hard)
Big sized tuber	Cooks fast/ easy to cook	Mealy
Smooth skin		Good taste
Firm/hard tuber		Good smell
No damage (e.g., cuts, holes from pest damage)		Yellow color
Good eyes (few eyes, shallow eye depth)		

Instrument-based texture and sensory analysis of boiled potato

Instrument-based texture evaluation of the boiled potato was performed for 16 genotypes (Table 1) of potato harvested from experimental plots located in Kiambu, Kenya (1900 m altitude). Marketable tubers with a good visual appearance were sampled, and then, after peeling, washing, draining, and steaming between layers of banana leaves, texture was measured using a texture analyzer (TMS Pilot, Mecmesin, West Sussex, UK). The steaming was carried out for 20 and 40 min in duplicate, each replicate consisting of six tubers per genotype. For each root, three points were demarcated 15 mm apart and measurements were taken at each point on the tuber, making a total of 9–18 measurements per genotype.

After calibration of the texture analyzer with a 5 kg load cell, measurement was carried out when the pieces were at 25 °C using a 60 ° conical penetration probe in compression mode to a depth of 10 mm at 1 mms^{-1} test speed. The results were presented in a graphic interphase using Emperor Force software supplied alongside the texture analyzer. The textural parameters that were evaluated were peak force (N), which represents the maximum force (hardness/strength) required to penetrate the sample to a depth of 10 mm, and the area (N·mm), which is represented by the area under the curve that corresponds to the work done to deform the sample by penetration to a depth of 10 mm.

The sensory evaluation of the texture of the boiled potato that was steamed for 40 min was conducted in duplicate using a standard procedure.[21] Fourteen trained panelists evaluated the following attributes: hardness in hand, moldability in hand, stickiness in hand,

Table 3. Prioritization of characteristics after gender and livelihoods assessment (G+ analysis)

Characteristic category	Characteristics	Gender impact scores (G+ tools)		Priority
		Do no harm score	Positive benefits	
Raw material	Red skin color	Reject (−2)	Nice to have (+1)	Not priority
	Moderately big tuber size	Neutral (0)	Required (+2)	Essential 'must have'
	Yellow flesh color	Neutral (0)	Required (+2)	Essential 'must have'
	Smooth skin	Neutral (0)	Required (+2)	Essential 'must have'
	No damage (e.g., cuts, holes from pest damage)	Reject (−2)	Neutral (0)	Not priority
	Firm tuber	Neutral (0)	Required (+2)	Essential 'must have'
	Good eyes (few eyes, shallow eye depth)	Neutral (0)	Required (+2)	Essential 'must have'
Processing	Easy to peel	Neutral (0)	Required (+2)	Essential 'must have'
	Cooks fast/easy to cook	Neutral (0)	Required (+2)	Essential 'must have'
Cooked/ready to eat final product	Moderately firm	Neutral (0)	Required (+2)	Essential 'must have'
	Mealy	Amend (−1)	Nice To Have (+1)	Requires mitigation plan/action
	Good taste	Neutral (0)	Required (+2)	Essential 'must have'
	Good smell	Neutral (0)	Nice To have (+1)	Recommended for further work

moistness in hand, crunchiness in mouth, mealiness in mouth, smoothness in mouth, uniform texture in mouth, fracturability in mouth, hardness in mouth, and moistness in mouth. They scored these traits on a scale of 0–10 according to the product profile and sensory lexicon developed for Uganda.[16] The data were cleaned according to the methods documented in earlier studies.[22]

High throughput: the spectral method

A spectral analysis was performed on a total of 30 potato genotypes harvested from experimental plots located in Kiambu, Kenya (1900 m altitude), and from the local market in Kampala, Uganda. Marketable-size tubers with good visual appearance were sampled. Spectra were collected from cooked, mashed samples. Calibrations were performed using reference data collected by a sensory panel as described above. Spectra were collected with the NIRS XDS (FOSS, Minnesota, USA) using ISIscan software (Infrasoft International, State College, PA, USA) in the wavelength range 400 to 2500 nm at 2 nm intervals. Three cooked and mashed tubers per genotype were selected for the spectral collection. Each mashed sample was then scanned in a cuvette, producing three spectra per genotype. The spectrum was expressed as log (1/R). Details of sample preparation and spectra collection are published in a standard operating procedure.[23]

Statistical analyses

Analysis of variance was used to determine significant differences between means using JMP Pro 15 software (SAS Institute Inc.,

Table 4. One-way ANOVA of instrument-based texture parameters of potato boiled for 20 and 40 min

		MS[a]			
Source of variation	DF	Peak force (20 min)	Area (20 min)	Peak force (40 min)	Area (40 min)
Genotype	17	24.9**	19.6**	4.8**	5.0**
Cooking replicate	1	181.6**	159.9**	7.9	10.3**
Root number	2	1.8	0.7	7	4.8
Root piece	2	1.7	0.01	2.4	1.3
Mean[b]		4.4	3.8	3.0	2.6

[a] Mean square.
[b] Mean based on genotypes.
** Significant at the 5% level.

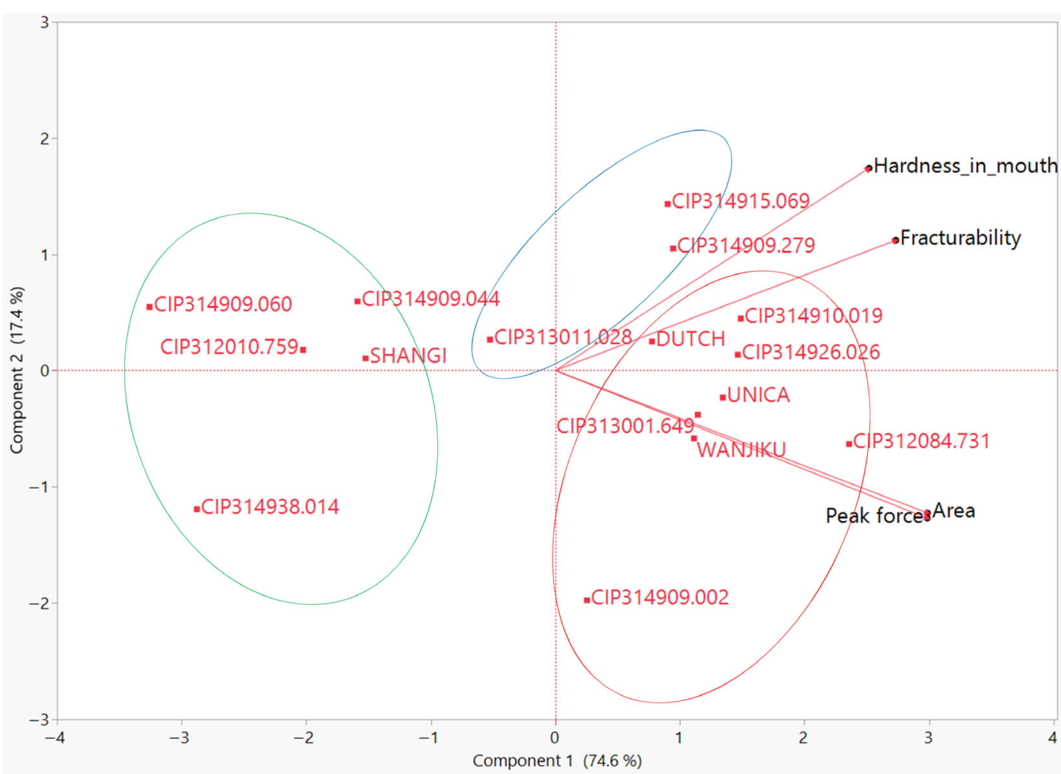

Figure 1. Principal component analysis (PCA) of sensory and instrument-based texture of Kenya boiled potato at 40 min cooking. The potato genotypes were clustered into good (red circle), intermediate (blue circle), and poor quality (green circle).

North Carolina, USA) and the means were separated by a Tukey test. Principal component analysis (PCA), bivariate correlations, discriminant analysis, and hierarchical clustering were used to determine clustering and association between variables.[22]

To visualize relationships between the spectral data and the potato genotypes, PCA was generated using mean scores for each replicate with the prcomp package, using the covariance option in R.[24] For spectral data, individual prediction models, using partial least squares regression (PLSR) in R,[25] were developed for each trait. The calibrations were performed using full cross-validation due to the limited number of samples. No spectral preprocessing was applied. The models were evaluated based on the coefficient of determination (r^2) and the root mean square error of cross-validation (RMSE).

RESULTS

Properties of boiled potato

The priority characteristics selected after triangulation are shown in Table 2. Priorities for high-quality raw material characteristics were red skin color, moderately large tuber size (optimal weight within 100–150 g), yellow flesh color, smooth skin, no damage, firm tuber, and good eyes (few eyes, shallow eye depth). During processing, priority was given to the characteristics such as 'easy to peel' and 'cooks fast/easy to cook'. The final food product (boiled potato) prioritized the characteristics such as 'moderately firm', 'fracturable (mealy)', 'good taste', 'good smell', and 'yellow color'.

Following gender analysis with the G+ tools, some characteristics were deprioritized (rejected), reprioritized (amended) or maintained as summarized in Table 3. Red skin color was deprioritized. Mealy was classified as *amend* or *proceed with caution*. Characteristics identified as *essential* or *must have* from a gender perspective were moderately large tuber size, yellow flesh color, smooth skin, firm tuber (raw), good eyes (few eyes, shallow eye depth), easy to peel, cooks fast/easy to cook, moderately firm (boiled), good taste.

Significant differences between genotypes were observed for both instrument-based textural attributes (peak force and area) at 20 and 40 min of cooking (Table 4). There was better discrimination among the genotypes at 20 min, probably because cooking for 40 min may almost have led to overcooking. However, at 20 min of cooking, repeatability was poor for both peak force and area, whereas at 40 min of cooking no significant differences were observed between the cooking replicates. The number of roots and the piece of roots from which the analyzed samples were obtained had no significant effects on the textural characteristics of the genotypes.

The first two components of the PCA of the combined data from the instrument-based and sensory texture explained 92% of the variation (Fig. 1). The instrument-based parameters peak force and area were significantly associated only with boiled potato fracturability in the mouth ($r = 0.63$ and $r = 0.60$, respectively) and hardness in the mouth ($r = 0.50$ and $r = 0.54$, respectively), for which genotypes such as CIP314910.019, CIP314926.026, CIP314909.002, CIP312084.731, CIP313001.649 clustered alongside good local landrace varieties such as Unica, Dutch and Wanjiku. The fracturability and hardness in the mouth can therefore be estimated better using the instrument-based texture parameters peak force and area (work done) for penetration. Genotypes CIP312010.759, CIP314909.044, and CIP314938.014 are associated closely with local landrace Shangi, which has a

Table 5. Correlation (below diagonal) and significance level (above diagonal) between instrument-based and sensory texture of Kenya boiled potato at 40 min cooking time

	Hardness by hand	Moisture release	Cohesiveness (moldability)	Stickiness	Fracturability in mouth	Hardness in mouth	Crunchiness	Moisture in mass	Mealiness	Smoothness	Uniformity of texture	Peak force	Area
Hardness by hand		0.4249	**0.0025**	0.2805	**0.0108**	**<0.0001**	0.0531	**0.0367**	0.2489	**0.0001**	0.7303	0.1079	0.1409
Moisture release	−0.2145		0.5286	0.1527	0.8853	0.7754	**0.033**	**0.006**	**0.0035**	0.7572	0.406	0.8737	0.9963
Cohesiveness (moldability)	**−0.7012**	0.1702		0.7457	0.1034	**0.0126**	0.1887	**0.0299**	0.1268	**<0.0001**	0.5462	0.4108	0.5461
Stickiness	0.2874	0.3747	0.0881		0.4476	0.1538	0.3562	0.1429	0.1374	0.6738	0.4732	0.6006	0.4049
Fracturability in mouth	**0.6176**	0.0392	−0.4221	0.2044		**0.0031**	0.0948	0.6638	0.4624	0.0929	0.4102	**0.0085**	**0.0136**
Hardness in mouth	**0.8768**	−0.0775	**−0.6075**	0.3738	**0.6901**		0.114	0.1797	0.5018	**0.0026**	0.6422	**0.0471**	**0.0309**
Crunchiness	0.4915	**0.5343**	−0.3464	0.2471	0.4319	0.4108		0.882	0.9247	0.0618	0.3103	0.7728	0.8851
Moisture in mass	**−0.5253**	**0.6536**	**0.5426**	0.3832	−0.1178	−0.3531	−0.0404		**0.0047**	0.114	0.7971	0.8514	0.9789
Mealiness	0.3061	**−0.6836**	−0.398	−0.3881	0.1979	0.1812	−0.0257	**−0.6673**		0.2298	0.2132	0.7278	0.5433
Smoothness	**−0.8111**	0.084	**0.8585**	−0.1141	−0.4341	**−0.6983**	−0.4768	0.4108	−0.3182		0.8157	0.7815	0.9525
Uniformity of texture	0.0936	0.2232	0.1631	0.1933	0.2213	0.1259	0.2708	0.0699	−0.3292	0.0634		0.8778	0.9656
Peak force	0.4172	−0.0432	−0.221	0.1417	**0.6327**	**0.5029**	0.0784	−0.0509	−0.0945	−0.0754	−0.0418		**<0.0001**
Area	0.385	0.0012	−0.1631	0.2237	**0.6018**	**0.5399**	0.0393	−0.0072	−0.1643	−0.0162	−0.0117	**0.9804**	

Note: Numbers in bold are significant at the 5% level.

poor association with fracturability in the mouth and hardness in the mouth. Other significant correlations were found between sensory textures such as hardness in the hand and hardness in the mouth ($r = 0.88$), smoothness in the mouth ($r = -0.81$), moldability in the hand ($r = -0.70$), fracturability in the mouth, and hardness in the mouth ($r = 0.69$) (Table 5). The characterization of the key sensory texture of the boiled potato may therefore have been perceived better by mouthfeel rather than hand feel.

Clustering into a three-class hierarchy (Fig. 2) showed that potato genotypes can be classified into good, intermediate, and poor texture-quality genotypes for boiled potato, considering that it was prioritized that a good genotype should be moderately firm and very fracturable. Alongside good landrace varieties such as Unica, Wanjiku, and Dutch, the genotypes CIP314909.002, CIP314910.019, CIP313001.649, CIP312084.731, and CIP314926.026 were clustered in the same class as good genotypes with relatively moderate firmness, requiring moderate work done for penetration, and good fracturability in mouth compared to other varieties. The intermediate genotypes CIP313011.028, CIP314909.279, and CIP314915.069 had texture attributes close to those of the good genotypes, while the poor genotypes CIP312010.759, CIP314909.044, CIP314938.014, CIP314909.060, and Shangi were soft (they had the least firmness), required the least work done for penetration, and had the least fracturability in mouth.

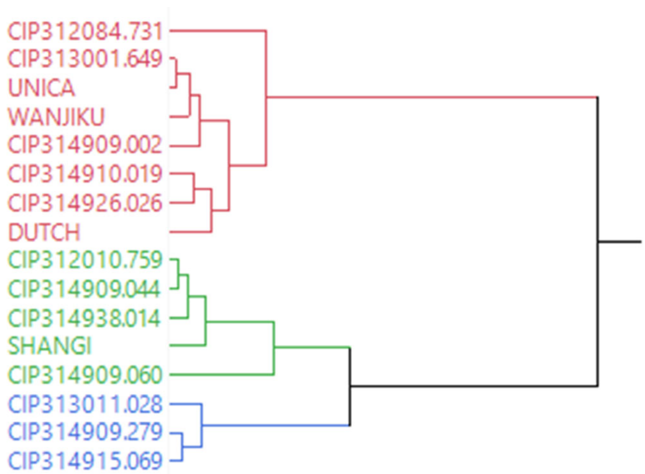

Figure 2. Three-class hierarchical clustering of potato genotypes into good (red), intermediate (blue), and poor quality (green) on the basis of instrument-measured texture of boiled potato cooked for 40 min.

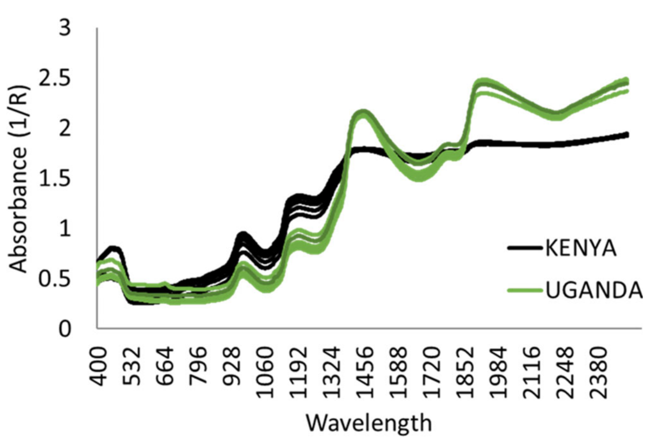

Figure 3. Five random spectra of near infrared spectroscopy reflectance of cooked-mashed potato samples collected from Kenya and Uganda.

Near-infrared spectra and predictions of sensory attributes

The spectra patterns of cooked mashed potato tubers from the sites in Kenya and Uganda are depicted in Fig. 3. There are five

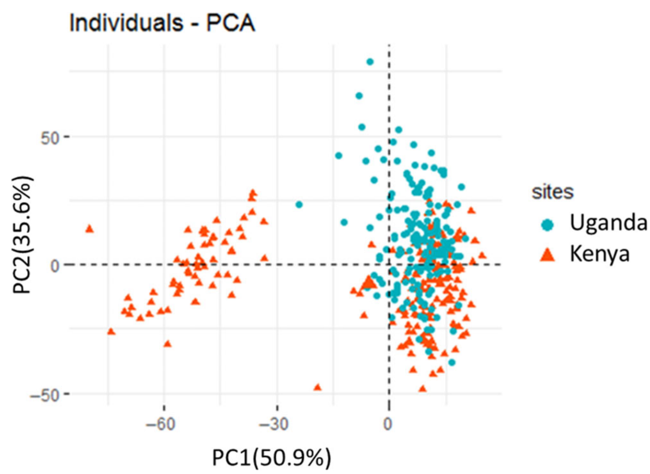

Figure 4. Principal component analysis (PCA) plot of the near infrared spectroscopy spectra from cooked-mashed potato tubers sampled from Kenya and Uganda.

Table 6. R^2, standard error of cross validation (SECV) and number of components of near-infrared spectrum calibrations for the sensory parameters of potato tubers based on full spectra collected from cooked-mashed tubers sampled from Kenya and Uganda

No.	Sensory parameter	r^2	SECV	#components
1	Potato aroma	0.04	0.63	1
2	Green vegetable aroma	0.06	0.57	1
3	Root vegetable aroma	0.04	0.42	1
4	Yellow color	0.70	0.63	3
5	Chalkiness	0.18	0.93	1
6	Homogeneity of color	0.48	0.53	3
7	Translucency	0.15	0.56	1
8	Potato flavor	0.02	0.71	1
9	Cooked carrot flavor	0.04	0.09	2
10	Green vegetable flavor	0.12	0.42	3
11	Root vegetable flavor	0.04	0.48	1
12	Sour taste	0.28	0.19	3
13	Bitter after taste	0.16	0.72	3
14	Hardness by hand	0.08	0.63	1
15	Moisture release	0.22	0.29	1
16	Cohesiveness (moldability)	0.09	0.55	1
17	Stickiness	0.14	0.49	2
18	Fracturability	0.20	0.67	2
19	Hardness in mouth	0.11	0.52	2
20	Crunchiness	0.06	0.26	1
21	Moisture in mass	0.40	0.89	2
22	Mealiness	0.19	0.82	1
23	Smoothness	0.28	0.71	3
24	Uniformity of texture	0.56	0.51	3

major peaks. The shape of the spectra from the different countries did not differ. A PCA (Fig. 4) calculated from the spectra (spectral range NIR) of the samples shows that 86.4% of the variance is explained by the two first PCs. The spectra in the potatoes collected from Kenya seemed to separate into two groups, where one group, clustered with the spectra collected on Ugandan samples and the other group grouped separately (Fig. 4). These two clusters may need further investigation in terms of the biochemical changes that occur during cooking. However, the significance of the clustering was not tested.

The different parameters that were calibrated are indicated in Table 6. Near-infrared spectra show some potential to predict selected sensory parameters such as yellow color ($r^2 = 0.70$), homogeneity of color ($r^2 = 0.48$), moisture in mass ($r^2 = 0.40$), as well as uniformity of texture ($r^2 = 0.56$). However, most of the other predictions were still poor.

DISCUSSION

There are several important criteria that act as a basis for selection of potato varieties. The results showed that (i) red potatoes were not prioritized; (ii) significant differences between genotypes were observed for textural attributes; and (iii) there was the potential of NIRS to predict color and selected texture attributes.

The assessed potatoes were yellow or red skinned. Red skin was deprioritized during the gender analysis. This was consistent with earlier studies reporting that the red-skinned variety Victoria was the least liked by consumers of boiled potato in Rakai and Kabale.[16] However, the perception of red-skin potatoes among consumers has been mixed; for example, most of the potato varieties grown and traded in Uganda have a red skin.[17] Red-skinned potatoes were among the preferred types in the potato growing areas of Uganda and Kenya.[16,26] These contrasting opinions suggest that using skin color alone as a determinant of quality or preference may be misleading, although it is a key trait in determining the marketability of potatoes.[16] This could be a result of differences in methodological approaches to the assessment of preference. The use of standard operating procedures to guide trial design, data collection, and data analysis[27] is therefore critical for establishment of cost-effective, reproducible, and comparable studies. However, skin color is normally used as a proxy for other characteristics. In Rakai and Kabale, for example, the red-skinned Victoria variety was associated with an undesirable soft and watery texture and was consequently the least liked by consumers of boiled potato.[16]

Breeding for red skin alone would therefore be restrictive because there are other good characteristics beyond skin color that need to be considered. Prioritizing this characteristic would not add significant benefits, especially for women. Mealiness was recommended for amendment because of the varying texture requirements of different end users and target consumers. For example, a variety with low mealiness would be desired for mashed potato (usually prepared for children), while the reverse would be true for chips preferred by the youth.[28] More research is therefore required to identify optimal mealiness for varying products to target the specific segmented demand. However, *mealy* and *good smell* were considered *nice to have* characteristics, thus underscoring their importance.

Traits relating to big tuber size, good texture of the skin, yellow flesh, ease of preparation, and good taste, consistently appear as essential traits in different regions,[16,29] and these could be considered as target breeding traits. Some of the requirements regarding the appearance of the tubers (optimal weight within 100–150 g, shallow eyes, and round or oval shape) are connected with a low percentage of the waste due to preprocessing, as well as processing efficiency,[30] and they would thus be important for women, who are mainly responsible for food preparation and cooking. Such traits could contribute to reducing drudgery and thus to a reduction of time poverty, which many women experience.[31] Overall, it is indicated that traits related to marketability, such as skin color, will appeal to both men and women. On the other hand, traits related to processing efficiency (easy to peel) and eating quality such as big size and mealiness will be more important to women given their productive and caregiving roles.[16]

Considering only Kenyan samples, the texture of potatoes steamed for 20 min was significantly harder (represented by peak force) and more work (represented by the area under the curve) was required to penetrate these potatoes than potatoes steamed for 40 min. Texture and volatiles changes are expected to occur during cooking treatments from processes such as gelatinization and lipid degradation.[32,33] Although the optimal time for cooking different potato genotypes has not yet been achieved, several methods have been described for measuring the 'cookedness' of potatoes, which correlates well with softening. For this study, it seems that, after 20 min, some genotypes remain unsatisfactorily cooked for panel evaluation, which potentially introduces preference bias.

Therefore, it may be preferable to assess genotypes based on the discrimination and repeatability of the texture of the boiled potato at more than 20 min of cooking. Studies that have attempted to optimize time for steaming potatoes recommend an intermediate cooking time of 21–24 min[34] or 30 min[32] prior to instrument-based and sensory tests, where discrimination among genotypes and repeatability between replicates could potentially be better guaranteed. At 40 min, discrimination between genotypes was not possible, suggesting that at this time the potatoes were overcooked. Cooking beyond optimal time changes the microstructure and composition inside the potatoes.[34] Even then, the cooking time depends on many factors including size of the tubers and the temperature used in cooking, for example, potatoes cooked at 100 °C can be overcooked at 15–20 min.[35]

In further reports,[36-38] textural protocols were used to distinguish potato and sweet potato genotypes and to find significant correlations with sensory texture. Additional studies could assess the potential to characterize key sensory texture of boiled potato by mouthfeel rather than hand feel. Substantial investment in methodology development and capacity is needed to bring greater coherence and enable cumulative learning about user perspectives to increase the fit iteratively between improved genotypes and user preferences.[39] Future studies should consider evaluating sensory and texture profiles for different cooking methods since preparation can differentially affect the profiles of the genotypes.[40]

The texture traits are normally assessed in the later stages of a breeding program after selection for more easily quantifiable traits, due to the cost of most conventional methods. Several non-destructive methods such as NIRS are available to enable selection during the early stages of breeding and these have also been described for characterizing different traits of potatoes as well as other crops, such as sweet potato.[23,35] In the current study, while NIRS shows the potential to predict color, most predictions still need improvement. One of the most important criteria for developing a robust NIRS calibration is that the natural variation of the parameter values of interest must be accounted for within the sample populations of the calibration and validation datasets.[41] It is therefore possible that the range of variation was less than optimal for a NIRS analysis of the parameters studied. Samples from Kenya were considered to be a source of variance, based on the existence of genotype by environmental interactions in sensory traits of potatoes,[42,43] to increase the predictability. Future studies will consider sampling at different seasons and sites within the country to enhance the variation further. Previous studies with potatoes have, for example, indicated the possibility of using NIRS to predict other desirable sensory parameters such as moistness, waxiness, firmness, and mealiness,[13,14] which could be the focus of future model improvement efforts for potato breeding in Uganda. However, it could also be that some sensory traits are simply poorly modeled using NIRS. Poor model calibrations for some sensory traits have, for example, been observed in cooked-mashed sweet potatoes even with relatively large sample sizes.[44] The use of a standard operating procedure on sample handling and spectra collection[23] is also important for the production of repeatable results.

A classification of sensory parameters based on spectral fingerprints should be tested, especially because the PCA clustering based on NIRS is consistent with that based on sensory data. Indeed, by defining thresholds, or classes, by criterion, it will be interesting to investigate the possibility of classifying the genotypes in order to carry out a rapid selection. Earlier studies, for example, were able to differentiate genotypes based on dry matter content.[13] For this, methods such as partial least square discriminant analysis (PLSDA), support vector machine (SVM), or soft independent modelling class analogy (SIMCA) can be applied to spectral and sensory data sets. Freeze drying of the samples may improve the precision of some predictions, since water may cause nonlinear responses due to the strong absorption signals in the NIR spectra.[45] Calibrations could also be enhanced using several data pre-processing approaches.[46]

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

EDITORIAL POLICIES AND ETHICAL CONSIDERATIONS

Research described in this manuscript (from laboratory through consumer preferences interviews and surveys) has been previously and formally approved by the competent authority(es) in Uganda. Written informed consent was obtained for all study participants and is available.

DATA AVAILABILITY STATEMENT

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

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