

Research Paper**Studies on Some Important Consumer and Processing Traits for Breeding Sweetpotato for Varied End-Uses.****ABSTRACT**

Aim: To determine the variability among the elite sweetpotato lines for root processing quality traits; to determine the heritability of each trait and the correlation among them; to determine the acceptability of the boiled and fried roots by sweetpotato consumers; and to identify easy-to-measure traits that are linked to consumer acceptability of sweetpotato roots.

Study design: Completely randomized design with three replications was used to evaluate fourteen elite sweetpotato lines for the root quality traits, and for the sensory characteristics of the boiled and fried roots.

Place and duration of study: Root samples were analyzed at the Biochemistry laboratory of the National Root Crops Research Institute, Umudike.

Methodology:

Fourteen advanced sweetpotato lines with varied were evaluated for processing traits such as dry matter, starch yield, flour yield and peel loss, and also for total carotenoid. Correlation analysis among the traits was carried out, and broadsense heritability for each trait was calculated. Sensory evaluation was carried out on roots of the lines using selected panelists. Culinary traits that most influenced acceptability of boiled and fried sweetpotato roots were determined using forward selection multiple regression analysis.

Results

There was significant ($P=0.05$) variation among the 14 advanced lines for dry matter, starch content, flour content and peel loss. Dry matter ranged between 24.16 and 34.17%, starch content between 17.58 and 22.0%, flour yield between 21.34 and 32.32% and peel loss between 18.17 and 24.01%. Correlation studies showed that dry matter had significant ($P<0.05$) correlation with starch and flour yield. There were significant ($P<0.05$) differences among the genotypes for root colour and general acceptability for boiled roots, and for root colour, mouth-feel, taste, aroma and general acceptability for fried roots. Forward selection multiple regression analyses for boiled and fried sensory traits identified fresh root colour as an easy-to-select trait to breed for consumer acceptability.

Keywords: sweetpotato, processing traits, heritability, regression analysis, sensory evaluation.

39 1. INTRODUCTION

40 Sweetpotato (*Ipomoea batatas* L. Lam) is the only species that produce tuberous roots out of the about
 41 500 other species of the genus *Ipomoea*. It is one of the most under-researched and under-utilised crops
 42 of its status. It is the 7th most important crop in term of annual production globally. China is the highest
 43 producer of sweetpotato with production figure of 75.6 million tonnes in 2011, followed by Tanzania and
 44 Nigeria with production figures of 3.57 and 2.73 million metric tonnes respectively (FAOSTAT, 2013).
 45 Nigeria is not an exporter of sweetpotato in any form, and as such, all the sweetpotato produced are
 46 usually consumed within the country. The major forms by which sweetpotato roots are consumed in
 47 Nigeria are by boiling and eating, frying, and as a sweetener in local non-alcoholic beverage called
 48 kunnu, which is popular in northern Nigeria. Other lesser forms include portage and pounding (Agbo and
 49 Ene, 1994). Industrial processing and utilization of sweetpotato is not common. However, the emergence
 50 of commercial sweetpotato fried chips in urban centers and cities, as well as the road-side fries are the
 51 first forms of commercial processing of sweetpotato that has evolved or is evolving in the country. Other
 52 root crops like cassava and potato (*Solanum tuberosum*) enjoy higher levels of processing than
 53 sweetpotato despite the fact that sweetpotato has shorter growth cycle of about 4 months, grows well in
 54 all agro-ecologies of Nigeria, is adapted to marginal lands, and the productivity in four months is as high
 55 as cassava's that takes twelve months.. While potato fries dominate the fries industry in major eateries
 56 across the country, cassava is used in the production of industrial starch, syrup as well as bakery
 57 products.

58 The development of new sweetpotato varieties with higher productivity has largely focused on increasing
 59 yield and resistance to biotic factors. Improving the processing qualities of sweetpotato has not enjoyed
 60 commensurate attention as increasing yield on farmers fields. This is probably why most of the cultivars
 61 available are only suitable for consumption as fresh roots, and not suitable for processing. The
 62 processing industries require high dry matter, high flour yield as well as high starch contents. These
 63 quality traits make such product fit for the downstream industries like textile, paper, pharmaceutical etc
 64 that use starch as raw materials, and the bakeries that require high quality flour. Developing new varieties
 65 that satisfy these processing requirements will rely on adequate information about the availability of the

genes in the gene pool of the breeding program, the relationships among the quality traits, identification of easy-to-measure trait that has large influence on acceptability, and the heritability of the root quality traits. Therefore, the objectives of this work are to determine the variability among the breeding lines in terms of root processing, dry matter content, starch content, flour content, peel loss and total carotenoid to determine the heritability and the relationships among these traits, to determine the acceptability of the boiled and fried roots, and to identify traits that are linked to consumer acceptability of sweetpotato roots, and that are easy to measure.

2. MATERIALS AND METHODS

Fourteen advanced sweetpotato lines of various flesh colours (white/cream, orange and yellow) were evaluated at Umudike, southeastern Nigeria in 2011. At harvest, three medium root samples (which are the dominant root size) from each plot were collected, bagged in black polythene, labeled and sent to the laboratory for immediate analyses. Each root was weighed before manual peeling, and re-weighed after peeling to determine peel-loss per root per plot. One root was re-bagged and store in the freezer in the dark for carotenoid content determination. The average peel-loss for each plot was calculated and recorded. The roots from each plot were sliced and mixed together, from which 100g was taken for dry matter, starch content (on wet basis) and flour content analyses. While working in the dark, the fresh roots in the freezer were retrieved, washed and used to determine the total carotenoid content ($\mu\text{g/g}$). The total carotenoid content ($\mu\text{g/g}$) was determined using the spectrophotometer method following the procedure of Rodriguez-Amaya (2001).

2.1 SENSORY EVALUATION

Some root samples from each advanced breeding line were also taken from the field for sensory (culinary) analysis. Some fresh roots from each line were boiled and some fried. Twenty untrained panelists who eat sweetpotato as their staple food naturally were invited to score each breeding line for storage root colour after boiling and frying, mouth-feel, taste, aroma and general acceptability. Each panelist was encouraged to rinse his/her mouth after tasting one or two samples so as to keep the taste buds fresh as much as possible before tasting the other samples. The panelists were asked to indicate

the degree of likeness of each line using a 9-point Hedonic scale, where 9= like extremely, 5=neither like nor dislike and 1= dislike extremely.

2.2 STATISTICAL ANALYSIS

All the statistical analyses carried out on the various data were done through the various procedures of SAS (1992). Analysis of variance was performed on the root processing quality traits using SAS GLM procedure, while Fisher's $LSD_{0.05}$ was used to separate the means of the advanced breeding lines for each trait. Correlation analysis was performed to determine the relationships that exist among the traits using SAS Proc. Corr command. Principal component biplot analysis between Principal component 1 and principal component 2 was generated for the processing traits using the SAS Princomp procedure. Phenotypic variance, genotypic variance and broadsense heritability estimates were calculated using the expected means square. The variance components were calculated from a linear function of the means squares of the ANOVA thus:

$$d^2e = MSE; d^2g = (MSG - MSE) / r; d^2p = d^2g + d^2e; \text{ and } h^2B = d^2g / d^2p; \text{ where}$$

d^2e = environmental variance component;

MSE = mean square of error;

d^2g = genotypic variance component;

MSG = mean squares of genotypes;

R = number of replicates;

h^2b = broadsense heritability.

Sensory evaluation data of the boiled and fried root samples were analysed, using SAS GLM procedure for randomized complete block design. Panelists were used as blocks. Fisher's $LSD_{0.05}$ was used to separate the means of the scores of each breeding line. Lastly, forward selection multiple regression analyses were performed on the sensory (culinary) traits to identify easy-to-select trait that has positive effect on general acceptability of sweetpotato varieties.

3. RESULTS AND DISCUSSION

3.1 ANALYSIS OF VARIANCE AND MEANS SEPARATION:

Table 1 shows the mean squares of the analysis of variance (ANOVA) of the processing quality traits (dry matter, starch content, flour content, peel-loss and total carotenoid content) of 14 advanced sweetpotato breeding lines. The advanced lines showed significant ($p=.05$) variation in dry matter, starch content, flour content, peel-loss and total carotenoid content. Dry matter content ranged between 24.16 and 34.17%, starch content was between 17.58 and 22.00%, flour content was between 21.34 – 32.32%, peel-loss between 18.17 – 23.31%, and total carotenoid between 0.58 and 20.82 $\mu\text{g/g}$ (fresh weight basis) (Table 2). Sweetpotato genotypes have been known to exhibit significant differences in dry matter, starch content and (β -) carotenoid content. Cervantes-Flores *et al* (2011) reported significant variation for dry matter ($p < 0.0001$), starch content ($p < 0.0001$) and β - carotenoid content ($p < 0.0001$). Dry matter (and auto-correlated traits to dry matter like starch and flour contents) often differ as a result of cultivar, location, climate, day length, soil type, pest and disease incidence and cultivation practices (Bradbury and Holloway, 1988). In their works, Cervantes-Flores *et al* (2011) reported dry matter range of 15 - 35%, while Vilama and Hariprakash (2011) reported dry matter range of 15.8 and 37.2%. The sweetpotato genotypes evaluated had dry matter content ranging from 24.16 to 34.16%. Cervantes-Flores *et al*. (2011) also reported starch content range of 5.4 – 21.9%. Our sweetpotato breeding lines had a range of 17.58 - 22.00%. Our breeding lines showed narrower values of dry matter and starch contents compared to the reports of the previous two authors, probably because our genetic materials at advanced stage of the breeding cycle had passed through many selection cycles for the measured traits.. More than 70% of our lines had $< 5 \mu\text{g/g}$ carotenoid, which was same as reported by Cervantes-Flores and his group.

3.2 CORRELATION ANALYSIS:

The phenotypic correlation coefficients among dry matter (%), starch content (%), flour content (%) and total carotenoid ($\mu\text{g/g}$ fresh weight basis) are presented in Table 3. Dry matter exhibited positive and significant correlation with starch content ($r = 0.52$, $p < 0.01$) and flour content ($r = 0.76$, $p < 0.0001$). As has been reported by many authors (Hernandez, 1963; Cervantes-Flores *et al.*, 2011), there was an

inverse and significant relationship between dry matter and total carotenoid ($r = -0.69$, $p < 0.01$), and between starch content and carotenoid content ($r = -0.64$, $p < 0.01$). The positive correlation between dry matter and flour content was expected as dried tuberous roots are milled to produce flour. Since dry matter content is influenced by starch content, it is also expected, as shown in Table 3, that there will be positive relationship between the two traits. Peel-loss had no significant ($p > 0.05$) correlation with any of the other traits. This is not unexpected as tuberous roots are usually peeled before other traits are assayed.

3.3 PRINCIPAL COMPONENT ANALYSIS:

Figure 1 shows the biplot between principal components 1 and 2. The biplot shows the relationships between processing traits and each genotype. The closeness of a genotype to a trait shows the strength of the relationship that exists between the genotype and the trait. TIS 87/0087 is related to high dry matter, high flour content and high starch content. So also are NRSP/05/7C, and to a lesser extent, Ex-Igbariam. CIP 440163 exhibited the highest peel-loss, just as CIP 440293 exhibited the strongest relationship with high total carotenoid. Ex-Oyunga and Centennial also show high correlation with carotenoid content. The negative relationship that exists between starch and dry matter contents on one hand and total carotenoid on the other explains the differential in planar orientation between them.

3.4 HERITABILITY ESTIMATES:

Heritability is a measure of observed phenotype that is accounted for by genetics. High heritability estimate for a trait depicts that the environment has little effect on the expression of that trait, and that breeding progress could be made by phenotypic observation and mass selection. All the traits under study showed high broadsense heritability (H_b) (Table 4). Each trait had $H_b > 0.90$ except starch content with H_b of 0.66. The intermediate starch h_b estimate suggests additive gene action, which is corroborated by the report of Dai *et al.* (1988), of an additive gene effect controlling starch content in sweetpotato. Jones (1977 reported heritability estimate ($h^2 = 0.65$) for dry matter, which was lower than the ones obtained from the genotypes evaluated, while Hahn *et al.* (1981) and Mwanga *et al.* (2002) recorded high broadsense heritability for resistance to sweetpotato virus disease. Total carotenoid is the chief determinant of the orange flesh colour in sweetpotato. Hernandez (1963) had found a highly significant

correlation between flesh colour and carotenoid content. This flesh colour, according to Jones (1977), exhibits high heritability.

3.5 SENSORY EVALUATION OF BREEDING LINES:

Farmer participatory selection is an approach that plant breeders use to involve farmers and consumers in the breeding process. It helps to enhance adoption of the new variety to be released later. The results of the sensory evaluation of boiled and fried storage roots of the advanced sweetpotato breeding lines are presented in Tables 5 and 6. For boiled roots, only four lines had the colour of their boiled roots disliked, while the root colour of the rest was either neither liked nor disliked, or liked. Only two lines had their feel in the mouth (mouth-feel) disliked, while the taste of three lines were also disliked. The aroma of Shaba alone was not accepted, while the same clone alone was not accepted across all traits evaluated (general acceptability).

For the fried storage roots, all the breeding lines were accepted for the five sensory (culinary) traits; only two lines were outrightly disliked for colour and mouth-feel, three for taste, and four for aroma. However, for general acceptability, only one line was rejected. As observed in the boiled roots, all the lines were either neither liked nor disliked, or liked. The general acceptability of all the lines except Shaba could be because the lines had undergone series of selection before now.

3.6 FORWARD SELECTION MULTIPLE REGRESSION ANALYSIS (FSMRA):

In plant breeding, few, easily-to-measure traits are often used as an indirect way of increasing the gain in a more difficult-to-measure trait if the former trait has a significant contribution to the phenotype of the latter. This technique increases the effectiveness and cost of breeding for difficult-to-measure trait. To effectively find such few traits that exert significant effect on a major trait, forward selection multiple regression analysis (FSMRA) is a tool that can be used. The statistical tool has been used by Afuape *et al.* (2011) to identify components of yield among 13 traits in sweetpotato. In order for us to identify one or two easy-to-measure sensory traits to enhance selection for consumer preferences at the early breeding stage when variability is still very high, the sensory tests data were subjected to FSMRA, using general acceptability as the dependent variable and other traits as independent variables. Tables 7 and 8 present

the results of the FSMRA for boiled and fried root samples respectively. For boiled roots, root flesh colour, mouth-feel and aroma had significant effects on general acceptability. For the fried root samples, only root flesh colour and taste significantly influenced general acceptability. Flesh colour is the only trait that is important in the regression models of the two food processing forms, and among all the sensory traits, it is the easiest to measure. Thus, fresh root flesh colour has given us a tool to use as an indirect selection criterion to develop varieties that will increase the adoption of sweetpotato for direct consumption, and for the emerging small and medium scale fry and crisp business in Nigeria. The fry and boil forms presently dominate sweetpotato utilization in Nigeria.

Table 1: Mean squares of the analysis of variance of dry matter, starch content, flour yield and peel loss of 14 advanced breeding lines of sweetpotato evaluated in 2011.

Source	Degree of freedom	Mean squares of the analysis of variance for each trait.				
		Dry matter	Starch yield	Flour yield	Peel loss	Total carotenoid
Genotypes	13	18.0289 ^{***}	3.3886 ^{**}	21.5679 ^{***}	6.1882 ^{***}	113.6939 ^{***}
Error	14	0.2532	0.6859	0.2507	0.1982	0.02348
Total	27					

Table 2: Means of dry matter, starch yield, flour yield and peel loss of 14 advanced sweetpotato breeding lines evaluated in the rainforest belt of Umudike in 2011.

Breeding lines	Dry matter (%)	Starch yield (%)	Flour yield (%)	Peel loss (%)	Total carotenoid (µg/g fresh weight basis)
TIS 87/0087	34.17	21.32	32.32	21.02	2.38
EX-IGBARIAM	33.33	21.20	27.89	21.74	2.73
NRSP/05/1B	30.15	22.00	29.46	18.98	n.a
NRSP/05/7C	30.14	20.26	29.01	19.21	1.88
NRSP/05/022	29.38	20.51	21.34	19.62	7.14
EX-OYUNGA	29.38	17.58	25.14	20.01	19.60
CIP 440163	28.08	19.65	24.53	23.31	1.61
NRSP/05/3D	27.04	19.22	24.72	18.21	0.58
SHABA	27.03	20.76	22.34	20.31	3.64
NRSP/05/3B	26.65	19.42	22.83	20.33	1.15
NRSP/05/10D	25.79	18.92	24.81	18.86	2.41
CIP 440293	25.44	18.04	21.60	18.17	20.82
CENTENNIAL	25.04	18.47	24.22	24.01	17.80
CIP 199034.1	24.16	20.23	22.73	19.70	3.02
FLSD _{0.05}	1.08	1.78	1.07	0.95	0.03

Table 3: Phenotypic correlation among four industrial quality traits of 14 sweetpotato advanced lines evaluated in the rainforest belt of Umudike in 2011.

	Dry matter (%)	Starch yield (%)	Flour yield (%)	Total carotenoid (µg/g fresh weight basis)
Peel-loss	0.1106 ^{ns}	0.0577 ^{ns}	0.0927 ^{ns}	0.06 ^{ns}
Dry matter		0.5206 ^{**}	0.7634 ^{***}	- 0.69 ^{**}
Starch content			0.4599 [*]	-0.64 ^{**}
Flour content				-0.30 ^{ns}

*** = P<0.0001, ** = P<0.01, ns = P>0.05.

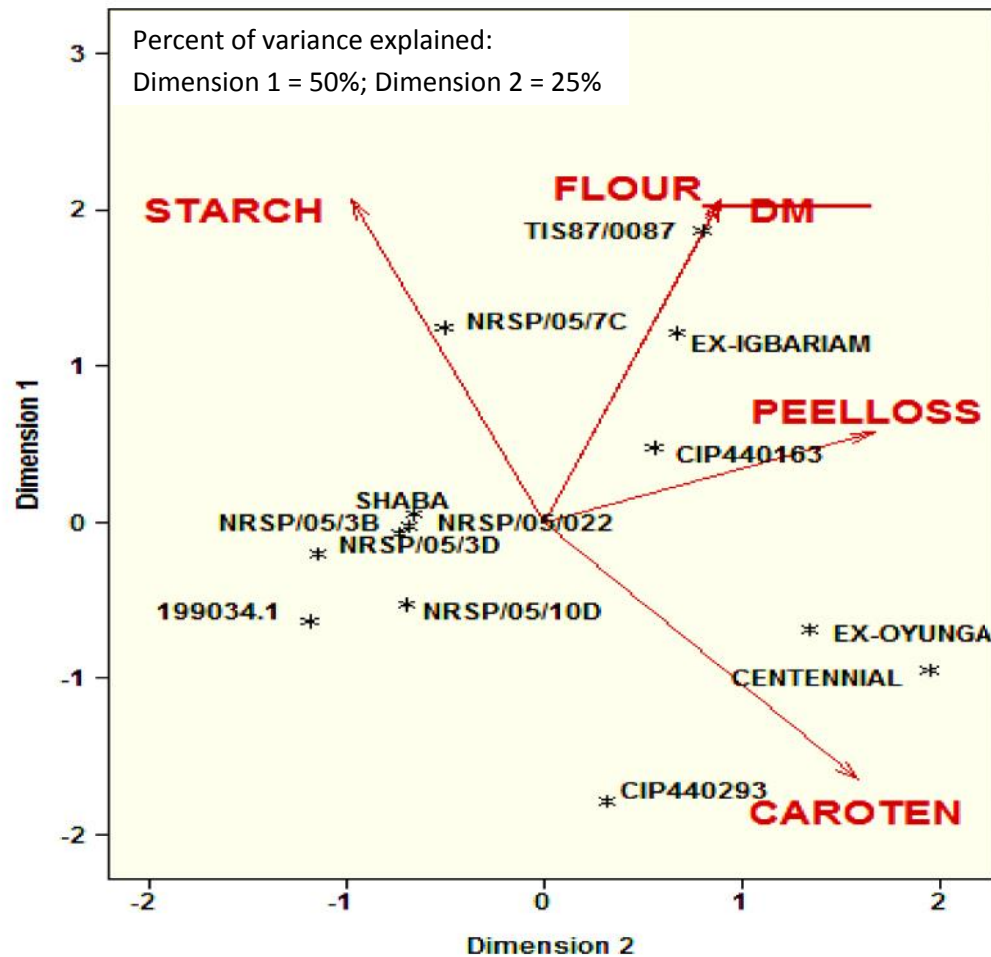


Figure 1: Principal component biplot showing the relationships between genotypes and the root processing quality traits.

Table 4: Broad sense heritability estimates for dry matter content, starch content, flour content, peel loss and total carotenoid in 14 sweetpotato breeding lines evaluated in 2011.

Trait	d^2_g	d^2_p	h^2_B
Dry matter content	8.89	9.14	0.97
Starch content	1.35	2.05	0.66
Flour content	10.66	10.91	0.98
Peel loss	3.00	3.19	0.94
Total carotenoid	56.84	57.86	0.98

Table 5: Sensory evaluation test for four culinary traits for boiled 14 advanced sweetpotato breeding lines in 2011.

Breeding lines	Colour	Mouth-feel	Taste	Aroma	General acceptability
TIS 87/0087	5.63	6.31	6.06	6.38	6.50
EX-IGBARIAM	5.56	5.88	5.75	6.19	6.31
NRSP/05/1B	5.81	6.00	6.19	6.00	6.38
NRSP/05/7C	6.38	5.88	6.13	5.81	6.81
NRSP/05/022	5.69	5.75	5.56	5.00	5.69
EX-OYUNGA	3.94	5.25	5.31	5.38	5.44
CIP 440163	3.88	5.63	5.44	5.56	5.44
NRSP/05/3D	4.44	5.44	5.63	5.25	6.13
SHABA	3.69	4.50	4.63	4.75	4.69
NRSP/05/3B	5.25	4.81	4.88	5.25	5.25
NRSP/05/10D	5.50	5.19	4.75	5.75	5.44
CIP 440293	6.31	5.50	5.13	5.38	5.69
CENTENNIAL	6.44	6.06	5.63	5.25	5.38
CIP 199034.1	4.56	5.63	5.44	5.38	5.69
FLSD _{0.05}	1.25	1.16	1.12	1.01	1.21

Sensory scores are on a 9-point hedonic scale where 1 = dislike extremely, 5 = neither like or dislike, and 9 = like extremely.

Table 6: Sensory evaluation test for four culinary traits for fried 14 advanced sweetpotato breeding lines in 2011.

Breeding lines	Colour	Mouth-feel	Taste	Aroma	General acceptability
TIS 87/0087	5.94	6.50	5.44	5.94	6.56
EX-IGBARIAM	6.81	6.25	5.81	5.56	6.25
NRSP/05/1B	6.44	6.50	5.81	5.50	6.38
NRSP/05/7C	6.13	5.81	5.69	4.94	6.60
NRSP/05/022	5.50	5.38	5.50	5.13	6.13
EX-OYUNGA	6.44	5.63	5.25	5.19	5.94
CIP 440163	5.44	6.25	5.63	6.38	6.50
NRSP/05/3D	5.06	5.00	4.56	4.81	5.56
SHABA	5.75	5.06	6.19	6.25	5.06
NRSP/05/3B	5.44	6.38	6.88	6.69	3.63
NRSP/05/10D	6.38	5.75	6.13	5.81	7.13

CIP 440293	3.94	4.63	3.44	3.63	4.56
CENTENNIAL	4.06	4.56	4.31	4.19	4.75
CIP 199034.1	5.94	5.94	6.31	7.19	7.56
FLSD _{0.05}	1.10	1.12	1.32	1.13	1.21

Sensory scores are on a 9-point hedonic scale where 1 = dislike extremely, 5 = neither like or dislike, and 9 = like extremely.

Table 7: Forward selection multiple regression analysis using General Acceptability as dependent variable against flesh colour, mouth-feel, taste and aroma for boiled roots.

Variable	Estimate	t value	Pr>t
Intercept	0.698	1.92	0.056
Root flesh colour	0.153	3.10	0.002
Mouth-feel	0.236	3.82	0.0002
Aroma	0.537	7.56	<0.0001

Regression equation for boiled roots is given as:

$$\text{General Acceptability} = 0.698 + 0.153 * (\text{Colour}) + 0.236 * (\text{Mouth} - \text{feel}) + 0.537 * (\text{Aroma})$$

Table 8: Forward selection multiple regression analysis using General Acceptability as dependent variable against flesh colour, mouth-feel, taste and aroma for fried roots.

Variable	Estimate	t value	Pr>t
Intercept	2.176	5.41	<0.0001
Root flesh colour	0.384	5.13	<0.0001
Taste	0.283	4.39	<0.0001

Other traits did not meet the entry criterion of leaving the model significant after entry at P<0.05.

Regression equation for fried roots is given as:

$$\text{General Acceptability} = 2.176 + 0.384 * (\text{Colour}) + 0.283 * (\text{Taste})$$

CONCLUSION

The wide variation among the genotypes for root processing quality traits depicts that different genotypes could be used for varied products. The high carotenoid content could positively impact the government's efforts at combating vitamin A deficiencies among rural and urban poor. All the processing traits evaluated are heritable and could easily be assayed with the high broadsense heritability estimates. The acceptability of most of the genotypes for boiled and fried food forms is a positive indication that the genotypes will be adopted as new varieties for production and consumption. Finally, the identification of the easy-to-measure root flesh colour as an important trait that positively influence consumer acceptability is a major achievement of this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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