Genetic and multivariate analysis of processing and yield traits in sweet potato for varied end-uses

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The present study aims to assess the genetic and multivariate component analysis of processing traits, yield traits, weevil resistance and other tuber traits in sweet potatoes based on the evaluation of 12 genotypes, including checks for yield and processing. Significant variability for tuber physical, processing and vine traits was observed. Nearly 75% of the genotypes had dry matter content (>30%), 50% had starch content (>20%), and none was resistant to sweet potato weevils. High genotypic and phenotypic variation, heritability and genetic advance were observed for tuber yield, tuber girth, total sugar and weight. Among the 13 phenotypic traits used in the present study, multivariate analysis identified only eight, contributing to 83.67% of the variation. UPGMA clustering yielded two major clusters and five sub-clusters. S27, Palakkad local, Trivandrum local, Sree Arun, S346, S27, Indira Madhur, EC 321693 and S444 were found suitable for processing. These genotypes can serve as breeding material for developing high-yielding varieties, thereby promoting the industrial utilization of sweet potatoes.

Keywords: Heritability, processing, sweet potato, variability, yield traits.

SWEET potato (*Ipomea batatas* L. Lam.), belonging to family Convolvulaceae, is grown across agro-climatic zones in tropical, subtropical and frost-free temperate climatic conditions. With an annual global production of 90 million tonnes (mt), it is considered the world's fifth most important crop[1]. Despite its origin in Latin America, the major share of the world's total sweet potato production is from the Asiatic belt, with China being the largest producer (84.01 mt), followed by Malawi (5.34 mt), Nigeria (2.91 mt) and Uganda (2.08 mt)[1]. In India, sweet potato is grown widely in the eastern region mainly for consumption. It is referred to as the 'Poor man's rich food', providing adequate nutrition at a cheaper cost compared to other staples[2]. In India, 1.16 mt of sweet potato is produced from states such as Odisha, West Bengal, Maharashtra and Andhra Pradesh. The average sweet potato yield in India is 10.2 t ha^{-1}.

Sweet potato can grow at altitudes ranging from sea level to 2500 m amsl and has a wide spectrum of skin and flesh colour variability, from white to yellow, orange and deep purple. Drought tolerance, shorter duration, nutrition enrichment and wider adaptability to different agro-eco-systems make it popular among the farming community and processing industries. Apart from being used as a staple, the diverse utilization of sweet potatoes has increased in the years, and new prospects of value addition in gained importance[3]. Sweet potato can be consumed as a fresh product or as processed, ready-to-eat food (i.e. chips and French fries) like potato[4]. The processing and utilization of sweet potatoes are limited to boiling, mashing and roasting in most parts of the world, except China, Japan, Vietnam, Malaysia, the Philippines and Indonesia. Sweet potato tubers are not exported to a large extent, unlike potatoes, where more than 50% of the yield is supplied to food industries, and exclusive varieties suitable for processing are available[5,6]. In order to follow the current food market trends, new sweet potato varieties with processing-related traits are essential. Hence, breeding for high-yielding varieties with good external and internal traits suitable for processing assumes significance. A well-planned breeding programme exploring the nature and magnitude of genetic variability and genetic control of the targeted traits related to processing is needed, and genetic analysis of the traits concerned is the most important step ahead. This study aimed to determine the magnitude of variability, heritability, genetic advance available for processing traits, yield and weevil resistance, and the association between the traits to develop sweet potato varieties suitable for processing and gain favour in the market and processing industries.

Materials and methods

Twelve sweet potato genotypes of varying flesh colour were evaluated for processing traits, cooking quality, weevil resistance and yield traits during 2021–22. Sree Arun was included as the yield check and S27 as a check for processing traits based on previous studies[3]. The field experiment was conducted at the Indian Council of Agricultural Research-Central Tuber Crops Research Institute (ICAR-CTCRI), Thiruvananthapuram, Kerala, India. The experiment was

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laid out in a randomized block design with three replications. The spacing followed was 0.9 × 0.9 m with a plant density of 12,345 plants per hectare. Fertilizer NPK 25 : 25 : 25 was given as basal application after first weeding, followed by NPK 25 : 0 : 25 as top dressing five weeks after planting. Harvesting was done four months after planting.

Data were recorded on tuber physical traits such as tuber length, tuber girth, tuber weight, tuber flesh colour, tuber smoothness, tuber cracking, tuber firmness, peel colour, uniformity in tuber size and shape, latex production and oxidation following the International Plant Genetic Resources Institute (IPGRI) sweet potato descriptor[7]. Dry matter content was determined by drying triplicates of 100 g samples[8]. Peel loss was measured as peel weight percentage of unpeeled fresh weight of the tubers. Flour yield was expressed as flour weight percentage of the unpeeled fresh tuber weight. Total starch and sugar were estimated using rapid titrimetric method[9]. Genotypes were screened for weevil resistance under natural infestation using a scale of 0 to 5, where 0 = no damage, 1 = 1–20% of the roots damaged, 2 = 21–40%, 3 = 41–60%, 4 = 61–80% and 5 = 81–100%. Data were recorded on vine internode length, vine internode diameter, tuber yield per plant and individual tuber weight. The sensory evaluation of boiled tubers of sweet potato genotypes was done, and parameters such as cooking time, consistency and texture of the boiled tubers, and development of undesirable colours on boiling were recorded. Browning or enzyme discolouration of harvested tubers was recorded from 0.5 to 6.5 h after slicing, and a scale of 1 to 5 was used, where 1 – no discolouration, 2 – light discolouration, 3 – fair discolouration, 4 – heavy discolouration and 5 – very heavy discolouration.

The data on processing traits were analysed following a completely randomized design to test for statistical significance. The data were subjected to principal component analysis (PCA), correlation and cluster analysis using SAS software[10]. The clustering of genotypes was done using UPGMA clustering following the NJ (neighbour joining) approach. The variance components, namely phenotypic variance ($\delta^2 p$) and genotypic variance ($\delta^2 g$) were determined from mean square values of ANOVA[11], and broad sense heritability was estimated as[12]:

$$h^2 = \delta^2 g / \delta^2 p.$$

The expected genetic advance was estimated as[13]:

$$\text{GA} = K \times \delta^2 p \times h^2,$$

where K is the selection differential at 5% selection intensity ($k = 2.063$). The genetic advance as percentage of mean (GAM) was computed as[13]:

$$\text{GAM (\%)} = \text{GA}/x \times 100,$$

where GA is the expected genetic advance and x is the grand mean of a character.

Results and discussion

Analysis of variance (ANOVA) for processing and yield traits, cooking time and weevil infestation, showed significant genotypic variability for processing traits among the 12 sweet potato genotypes analysed.

Tuber physical traits

The physical properties of sweet potatoes are crucial for designing efficient machinery for its handling, conveying, grading, processing and packaging[14,15]. The present study analysed the physical traits of sweet potato genotypes, revealing significant variability. Good root shape and larger size are essential for making chips. Tuber shape was mostly elliptic or obovate, with slight variation observed in Trivandrum local and Sree Bhadra. Most tubers weighed 210 g, making them suitable for processing and consumer preference[16]. The flesh colour variants observed were dark yellow to white, whereas the skin colour variants were dark purple, purple–red, yellow, pink and cream; these variants are usually preferred by majority of sweet-potato consumers[17]. Latex production and oxidation of tubers after slicing varied from less (S1248, Sree Varun and Indira Madhur) to abundant (Palakkad local, S27 and Sree Arun).

Processing traits

The study analysed the processing traits of sweet potato genotypes, revealing significant variability for dry matter content, total starch, total sugar, peel loss and flour yield (Table 1). The dry matter content varied from 24.76% (S346) to 37.23% (Trivandrum local), total starch from 18.70% (S1248) to 23.52% (Sree Arun), total sugar from 1.57% (S1248) to 4.95% (Sree Arun), peel loss from 10.65% (S346) to 19.41% (S1258) and flour yield from 26.60% (Sree Varun) to 41.87% (Palakkad local). The dry matter content and total starch content exhibited significant variability, with 75% of the genotypes with dry matter content of >30% and 50% of the genotypes with starch content of >20%. This included EC321693, S444, Sree Varun, Trivandrum local, Indira Madhur and Palakkad local. These sweet potato genotypes can be used for making fries, chips and high-quality purees[18,19]. Sree Arun and Palakkad local, with high starch content equivalent to S27 (processing quality check), can be used for starch extraction and, therefore, for the production of noodles, vermicelli and many processed products such as paper, cosmetics and adhesives. Total sugar variation among the studied genotypes was wide, ranging from 1.57% to 4.95%. Genotypes such as S1248, S444 and S346, with low sugar and moderate starch content, can be used for chips and fries[20].

Table 1. Mean values of processing traits, cooking, yield traits and weevil incidence of 12 sweet potato genotypes

Genotype	Dry matter content (%)	Total starch (%)	Total sugar (%)	Peel loss (%)	Flour yield (%)	Tuber yield (t ha^{-1})	Vine internode length (cm)	Vine internode diameter (cm)	Individual tuber weight (kg)	Cooking time (min)	Mean tuber length (cm)	Mean tuber girth (cm)	Weevil infestation score
S1248	32.20^{abc}	18.70^{d}	1.57^{g}	15.07	33.93^{bcde}	5.35^{e}	2.50^{d}	1.03^{hi}	0.36^{b}	5.67^{cd}	7.03^{e}	7.60^{f}	1.00^{d}
EC321693	35.47^{ab}	20.90^{bcd}	2.30^{cd}	14.46	32.27^{cdef}	0.95^{fg}	5.60^{bc}	1.40^{ef}	0.02^{e}	5.67^{cd}	16.57^{a}	16.17^{c}	1.00^{d}
S444	32.07^{abc}	20.62^{bcd}	1.77^{fg}	11.07	28.93^{ef}	4.32^{e}	1.05^{e}	2.44^{a}	0.02^{e}	5.67^{cd}	11.33^{bcde}	9.17^{ef}	2.33^{b}
Sree Varun	33.60^{abc}	21.52^{abc}	2.21^{cd}	15.09	26.60^{f}	12.06^{b}	5.86^{b}	1.20^{fgh}	0.09^{de}	6.67^{b}	16.40^{ab}	20.90^{a}	2.33^{b}
Trivandrum local	37.23^{a}	20.62^{bcd}	2.28^{cd}	15.04	34.47^{bcde}	5.56^{de}	5.67^{bc}	1.97^{c}	0.79^{a}	8.33^{a}	10.60^{cde}	21.73^{b}	2.67^{ab}
Indira Madhur	33.00^{abc}	20.34^{bcd}	2.17^{cde}	16.83	31.20^{def}	6.87^{d}	5.00^{bc}	1.51^{de}	0.15^{de}	6.33^{bc}	16.57^{a}	13.60^{cd}	2.33^{b}
S346	24.76^{d}	19.09^{d}	1.89^{ef}	10.65	32.36^{cdef}	0.45^{g}	5.33^{bc}	1.10^{ghi}	0.13^{de}	6.00^{bcd}	11.27^{cde}	7.13^{f}	1.00^{d}
S1258	31.13^{bc}	19.42^{cd}	2.13^{de}	19.41	38.80^{ab}	12.51^{b}	5.30^{bc}	1.87^{c}	0.21^{bcd}	5.33^{d}	9.27^{de}	8.27^{ef}	2.00^{bc}
Sree Bhadra	31.55^{bc}	19.19^{d}	2.43^{c}	14.83	26.62^{f}	2.10^{f}	4.51^{c}	1.28^{fg}	0.18^{cde}	5.33^{d}	9.47^{de}	11.23^{de}	1.33^{cd}
Palakkad local	31.53^{bc}	22.06^{ab}	2.42^{cd}	16.08	41.87^{a}	6.79^{d}	5.53^{bc}	1.63^{d}	0.10^{de}	6.00^{bcd}	15.03^{abc}	9.47^{de}	3.33^{a}
S27	29.97^{cd}	21.85^{ab}	4.05^{b}	15.94	32.36^{cdef}	10.70^{c}	8.37^{a}	1.10^{ghi}	0.18^{de}	6.00^{bcd}	9.70^{de}	15.50^{c}	2.00^{bc}
Sree Arun	25.05^{d}	23.52^{a}	4.95^{a}	15.38	35.84^{abcd}	21.40^{a}	3.23^{d}	2.20^{b}	0.35^{bc}	6.00^{bcd}	12.47^{abcd}	21.80^{b}	2.67^{ab}
Maximum	37.23	23.52	4.95	19.41	41.87	21.4	8.37	2.2	0.79	8.33	16.4	21.8	3.33
Minimum	24.76	18.7	1.57	10.65	26.6	0.95	1.05	1.03	0.02	5.33	7.03	7.13	1
Mean	31.46	20.65	2.51	14.95	33.38	7.42	4.82	1.55	0.21	6.08	12.41	14.75	2
SE (mean)	1.81	0.71	0.09	2.22	2.07	0.43	0.42	0.07	0.05	0.27	1.73	1.14	0.29
CD 5%	5.34	2.1	0.28	6.5ns	6.1	1.28	1.24	0.2	0.17	0.81	5.1	3.35	0.84
CD 1%	7.27	2.87	0.38	8.91ns	8.31	1.74	1.69	0.28	0.23	1.1	6.95	4.57	1.19
General mean	31.46	20.65	2.51	14.99	33.38	7.42	4.83	1.55	0.21	6.08	12.14	14.75	2
P-value	0.0025	0.0062	<0.0001	0.3854	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0057	<0.0001	0.0001
CV (%)	9.93	6.42	6.7	25.33	10.72	10.66	14.82	7.98	46.93	7.7	24.78	13.16	26.11

*Means followed by the same superscripts are not significantly different ($P < 0.05$). Different letters in the same column represent statistically different results ($P < 0.05$).

The peel loss reported in this study was 19.1%, which is comparable to 18% reported in other studies[21,22]. Palakkad local, with a high flour yield (41.8%), can be effectively used to produce a variety of processed foods since flour yield affects the properties, nutritional value and colour of these foods[23].

Cooking time, boiled tuber traits and browning/ enzyme discolouration

Cooking quality is crucial for tuber consumption[24], and S27, with a cooking time of 5–6 min with no discolouration on boiling, was found suitable for boiling and mashing. Tuber consistency varied from watery (Indira Madhur) to moderately hard (Sree Arun), and texture varied from dry (Sree Arun and Sree Bhadra) to very moist (Indira Madhur). Sweet potato tubers are prone to browning or discolouration during post-harvest processing and storage, caused by endogenous phenolic compounds oxidation reaction[25]. After slicing, genotypes were categorized into light discolouration (Indira Madhur and Sree Bhadra), fair discolouration (Sree Arun, S27, Trivandrum local and 1258) and heavy discolouration (1248, Sree Varun and Palakkad local). These genotypes can be easily processed into various products.

Yield traits

Tuber yield ranged from 0.45 to 21.40 t ha^{-1}, with high yields for Sree Arun, S1258 (12.51 t ha^{-1} each), and Varun (12.06 t ha^{-1} each). Low yields were found for S346 (0.45 t ha^{-1}), EC321693 (0.95 t ha^{-1}) and Sree Bhadra (2.10 t ha^{-1}).

Vine characters

The vine internode length ranged from 1.05 (S444) to 8.37 cm (S27), whereas the vine internode diameter ranged from 1.03 (S1248) to 2.20 cm (Sree Arun). With respect to vine characters, S27 was reported to have a high value for vine internode length, followed by Sree Varun, Trivandrum local and Palakkad local. These genotypes can be used as dual-purpose varieties.

Weevil resistance

Screening for weevil resistance is crucial as it affects storage root damage intensity, leading to low productivity[26]. We found variable resistance among the tested sweet-potato genotypes, categorizing them into moderately resistant (Sree Bhadra, S1248, EC 321693 and S346), moderately susceptible (Trivandrum local, S444, Sree Varun, Indira Madhur, S1258, S27 and Sree Arun) and susceptible (Palakkad local). None of the genotypes was resistant to sweet potato weevil.

Genetic parameters

Higher phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) values for individual tuber weight and tuber yield indicate their reliability for genetic improvement. Heritability estimates ranged from 0.03 (peel loss) to 0.98 (tuber yield), with high estimates for tuber yield, total sugar, vine internode diameter and mean tuber girth, indicating genetic control rather than environmental effect on these traits. The maximum expected genetic advance was observed for individual tuber weight, followed by tuber yield, tuber girth and vine internode length. The range of genetic advance as a percentage mean was 1.68 (peel loss) to 171.93 (individual tuber weight). Characters like tuber yield, tuber girth, total sugar and tuber weight have high genotypic and phenotypic variation, heritability and genetic advance, making them suitable for improvement in sweet-potato breeding programmes.

Correlation

A highly significant positive correlation was reported between total starch, dry matter content and other traits[3,27]. A highly significant positive correlation was observed between total starch and dry matter content (0.77), individual tuber weight and cooking time (0.72), as well as tuber yield and total sugar (0.73). Total starch content significantly correlated with tuber girth (0.71) and weevil infestation (0.68). There was a significant positive correlation between tuber girth and cooking time (0.60). A significant negative correlation was observed between matter content and total sugar (–0.46), flour yield and total sugar (–0.4), dry matter content and tuber yield (–0.34), dry matter content and vine internode diameter (–0.49) and individual tuber weight and mean tuber length (–0.42). The negative correlation between dry matter content and tuber yield can be explained by the variability for crude fibre content among the sweet potato genotypes studied[17].

Principal component analysis

In this study, five principal components (PC1, PC2, PC3, PC4 and PC5) were identified, with PC1 contributing 30.71% of the total diversity, PC2 19.78%, PC3 1.83%, PC4 11.09% and PC5 8% of the total variation among the 12 accessions tested. Strong correlations were observed between the PCs and phenotypic traits (Figure 1). Among the 13 phenotypic traits used in the present study, PCA identified only eight, namely total starch content, total sugar content, tuber yield, vine internode length, vine internode diameter, individual tuber weight, cooking time and weevil infestation score with strong correlations with the five PCs. These are important to differentiate sweet-potato genotypes similar to earlier reports[28].

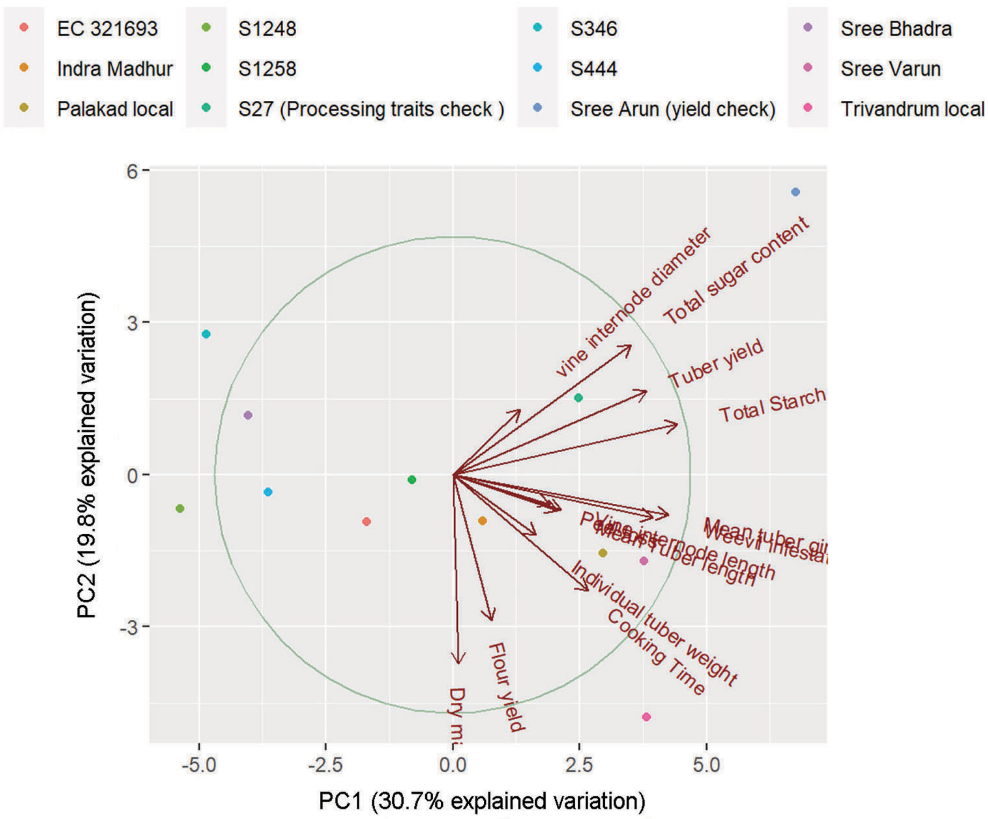

Figure 1. PCA biplot showing the relationship between processing traits and sweet potato genotypes.

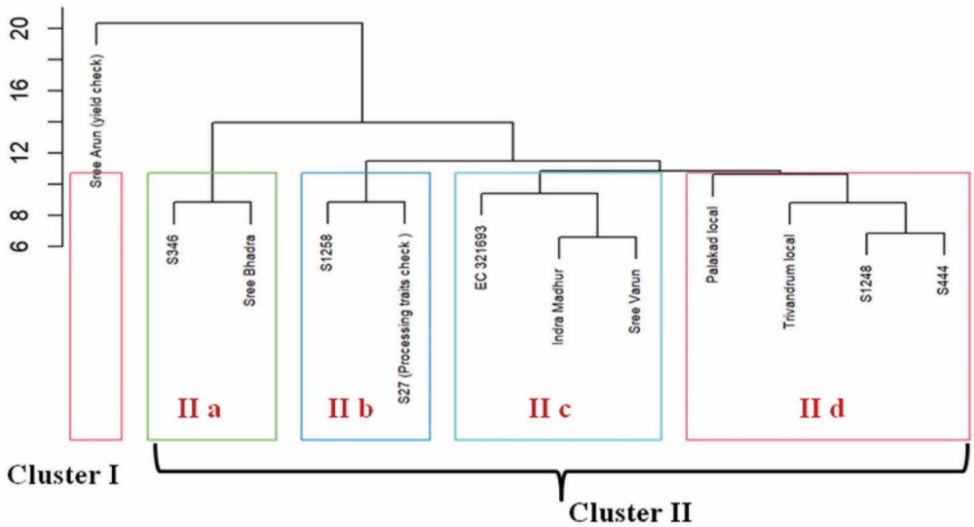

Figure 2. UPGMA dendrogram based on physical traits, processing, yield, cooking-time and weevil infestation score traits of sweet potato genotypes.

Genetic relationships of sweet potato genotypes based on phenotypic characteristics

UPGMA clustering using the NJ approach resulted in two major clusters (I and II) divided into five sub-clusters (Ia, Ib, IIa, IIb, IIc and IId). Cluster I contained Sree Arun, while Cluster II included other genotypes (Figure 2). High-starch and low-starch genotypes were found in separate sub-clusters, with Sree Arun as a cluster with high starch and yield. S1258 was found along with S27 in the same cluster, showing its genetic potential for the selection of high-starch and low-sugar sweet potato varieties. The clustering was distinctive for starch content and weevil resistance, allowing genotypes from divergent clusters to be used as heterotic pools in breeding programmes.

Conclusion

The present study revealed significant variability in processing, yield, cooking time and weevil resistance. Based on performance per se, Sree Arun, Palakkad local and S27 were found suitable for starch extraction and for making noodles, vermicelli, paper, cosmetics and adhesives; S1248, S444 and S346 for chips and fries; EC 321693, S444, Palakkad local, Trivandrum local and Indira Madhur for chips and puree preparation, and S27 for boiling and mashing. This study demonstrates the suitability and potentiality of different sweet-potato genotypes for various processing methods and products, making them suitable for breeders, farmers and processors for various end-uses and nutritional security.

1. http://faostat.fao.org (accessed on 18 October 2022).
2. Srinivas, T., Economics of sweetpotato production and marketing. In *The Sweetpotato* (eds Loebenstein, G. and Thottappilly, G.), Springer, 2009, pp. 235–267.
3. Visalakshi, C., Anil, S. R., Sheela, M. N., Hegde, V., Jyothi, A. N. and Sreekumar, J., Genetic variation for important processing traits and identification of potential parents for developing hybrid clones suitable for processing in sweet potato (*Ipomoea batatus* L. Lam). *S. Afr. J. Bot*., 2021, **141**, 255–264.
4. Frusciante, L., Barone, A., Carputo, D., Ercolano, M. R., Della Rocca, F. and Esposito, S., Evaluation and use of plant biodiversity for food and pharmaceuticals. *Fitoterapia*, 2000, **71**, 66–72.
5. Gupta, V., Luthra, S. and Singh, B., Breeding potato for value addition: a comprehensive approach for sustainable potato production**.** In Proceedings of the National Seminar on Emerging Problems of Potato, Central Potato Research Institute, Shimla, 2014.
6. Luthra, S. K., Gupta, V. K., Kaundal, B. and Tiwari, J. K., Genetic analysis of tuber yield, processing and nutritional traits in potato (*Solanum tuberosum*). *Indian J. Agric. Sci.*, 2018, **88**(8), 1214–1221.
7. Huaman, Z., Descriptors for sweet potato. International Board for Plant Genetic Resources CIP, AVRDC & IBPGR, Rome, Italy, 1991.
8. AOAC, *Official Methods of Analysis, 17th Edn*, Association of Official Analytical Chemists, Washington, DC, USA, 2010.
9. Moorthy, S. N. and Padmaja, G., A rapid titrimetric method for the determination of starch content of cassava tubers. *J. Root Crops*, 2002, **28**(1), 30–37.
10. SAS/STAT (9.4 M8), SAS Institute Inc, Cary, NC, USA, 2020.
11. Burton, W. G. and Devane, E. H., Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. *Agron. J*., 1953, **45**, 478–481.
12. Allard, R. W., *Principle of Plant Breeding*, John Wiley, New York, USA, 1960, p. 485.
13. Johnson, H. W., Robinson, H. F. and Comstock, R. E., Estimation of genetic and environmental variability in soybeans. *Agron. J.*, 1955, **47**, 314–318.
14. Tabatabaeefar, A., Size and shape of potato tubers. *Int. Agrophys*., 2002, **16**(4), 301–305.
15. Balami, A. A., Adebayo, S. E. and Adetoye, E. Y., Determination of some engineering properties of sweet potato (*Ipomoea batatas*). *Int. J. Appl. Nat. Sci.*, 2012, **1**(1), 67–77.
16. Rodriguez, M., Oses, J., Ziani, K. and Mate, J. I., Combined effect of plasticizers and surfactants on the physical properties of starch based edible films. *Food Res. Int*., 2006, **39**, 840–848.
17. Troung, V. D. and Avula, R. Y., Sweet potato purees and powders for functional food ingredients. In *Sweet Potato: Post Harvest Aspects in Food*, Nova Science Publishers, New York, 2010, pp. 117–161.
18. Truong, V. D., Deighton. N., Thompson, R. L., McFeeters, R. F., Dean, L. L., Pecota, K. V. and Yencho, G., Characterization of anthocyanins and anthocyanidins in purple fleshed sweet potatoes by HPLC, DAD and LC/ESI/MS. *J. Agric. Food Chem.*, 2010, **58**, 404–410.
19. Yencho, G. C. *et al.*, 'Covington' sweet potato. *Hortscience*, 2008, **43**, 1911–1914.
20. Kays, S. J., Wang, Y. and McLaurin, W. J., Chemical and geographical assessment of the sweetness of the cultivated sweet potato clones of the world. *J. Am. Soc. Hortic. Sci*., 2005, **130**, 591–597.
21. Singh, K. K. and Shukla, B. D., Abrasive peeling of potatoes. *J. Food Eng.*, 1995, **26**, 431–442.
22. Afuape, S. O., Nwankwo, I. I. M., Omodamiro, R. M., Echendu, T. N. C. and Toure, A., Studies on some important consumer and processing traits for breeding sweet potato for varied end-uses. *Am. J. Exp. Agric*., 2014, **4**, 114–124.
23. Derege, B., Girma, A., Mamo, D. and Chalchisa, T., Functional properties of sweet potato flour and its role in product development: a review. *Int. J. Food Prop*., 2020, **23**(1), 1639–1662.
24. Moorthy, S. N., Naskar, S. K., Shanavas, S., Radhika, G. S. and Mukherjee, A., Physico-chemical characterization of selected sweet potato cultivars and their starches. *Int. J. Food Prop*., 2010, **13**, 1280–1298.
25. Lim, W. Y. and Wong, C. W., Inhibitory effect of chemical and natural anti-browning agents on polyphenol oxidase from ginger (*Zingiber officinale* Roscoe). *J. Food Sci. Technol*., 2018, **55**(8), 3001–3007.
26. Jansson, R. K., Bryan, H. H. and Sorensen, K. A., Within-vine distribution and damage of sweet potato weevil, *Cylas formicarius elegantulus* (Coleoptera: Curculionidae), on four cultivars of sweet potato in Southern Florida. *Fla. Entomol*., 1987, **70**(4), 523–526.
27. Afuape, S. O., Okocho, P. I. and Njoku, D., Multivariate assessment of the agromorphological variability and yield components among sweet potato (*Ipomoea batatas* (L.) Lam) landraces. *Afr. J. Plant Sci.*, 2011, **5**(2), 123–132.
28. Fongod, A. G. N., Mih, A. M. and Nkwatoh, T. N., Morphological and agronomical characterization of different accessions of sweetpotato (*Ipomoea batatas*) in Cameroon. *Int. J. Agric. Sci.*, 2012, **2**, 234–245.

ACKNOWLEDGEMENT. We thank ICAR-CTCRI, Thiruvananthapuram for infrastructure and financial support under the Institute Project fund.

Received 22 December 2022; re-revised accepted 29 August 2023

doi: 10.18520/cs/v125/i10/1093-1098