J.Natn.Sci.Foundation Sri Lanka 2025 53 (1): 57 - 72
DOI: http://dx.doi.org/10.4038/jnsfsr.v53i1.12174

RESEARCH ARTICLE

Plant Genetics

Evaluation of genotypic variability and yield performance of selected indigenous and improved *Ipomoea batatas* L. genotypes under poly sack cultivation

MFZ Safwa[1], TN Samarasinghe[1], AN Wijevardhana[1], HAPA Shyamalee[1], AL Ranawake[2*]
[1] *Agriculture Research Station, Thelijjawila, Sri Lanka.*
[2] *Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Mapalana, Sri Lanka.*

Submitted: 05 May 2024; Revised: 16 January 2025; Accepted: 21 January 2025

Abstract: The genotypic diversity of *Ipomoea batatas* L. is important to enhance resilience against diseases, adaptability to diverse environments, and to provide a broader nutritional profile to address food security challenges. Poly sack cultivation is often considered superior to field cultivation because it offers better control over environmental factors. This study examined the diversity among seventeen indigenous *I. batatas* accessions compared to five improved varieties through comparative yield analysis under poly sack cultivation. Thirty-three traits were recorded following the standards set by the International Potato Center. Principal component (PC) analysis, cluster analysis and correlation analysis were performed using IBM SPSS 25 statistical software. The four PCs that exceeded Eigenvalue one, explained 76.55% of the total variance. Storage root characteristics and vine diameter contributed to PC1, while leaf, petiole, internodal and vine characteristics contributed to PC2. Four distinct clusters were identified at cluster distance ten in the hierarchical agglomerative clustering using Ward linkage. Cluster II comprised the thickest storage roots. Accessions *TJ19, TJ11, TJ1*, and *TJ20* were the best-performing under poly sack cultivation yielding 2.93 kg, 2.43 kg, 2.42 kg and 2.27 kg, respectively. These genotypes show potential for promoting urban cultivation of *I. batatas* in poly sack cultivation. Yield variation of *I. batatas* genotypes under different cultivation techniques must be considered when integrating them into farming systems since the best-yielding genotypes in field cultivation did not necessarily achieve the highest yields in poly sack cultivation. The existing flesh colour, shape of storage root, yield variation, and canopy characteristics can be utilized for breeding purposes in the future. Future studies should focus on controlling vegetative growth to optimize yield through pruning or trailing, as many vegetative growth parameters were inversely correlated with yield.

Keywords: Agro-morphological characteristics, field and poly sack cultivation, *Ipomea batatas*, PCA, yield determinants of *Ipomea batatas.*

INTRODUCTION

Sweet potatoes (*Ipomoea batatas*) are believed to have originated in Central and South America, with evidence of their cultivation dating back over 5,000 years. The Incas in Peru and the Aztecs in Mexico, were among the first to cultivate and consume sweet potatoes (Nedunchezhiyan & Ray, 2010). Christopher Columbus is credited with introducing sweet potatoes to Europe (Kingsbury, 1992). According to De Silva (2020), the Batatas genus is locally called 'Sweet potato'. *I. batatas* is commonly perceived as indigenous to Sri Lanka due to its longstanding cultivation as an important traditional food (Premathilake, 1999).

The *I. batatas* genome is typically hexaploid with a chromosome count of 2n = 6x = 90; some studies have documented the existence of tetraploid variants with 2n = 4x = 60 (Roullier *et al.*, 2013). Globally, 8 million hectares harvest 89 million tons of *I. batatas* (United Nations, 2020).

* Corresponding author (lankaranawake@hotmail.com; https://orcid.org/0000-0003-0517-9911)

The Department of Agriculture in Sri Lanka, has introduced several improved *I. batatas* varieties, but none of the varieties have been developed for biotic or abiotic tolerances.

I. batatas has an advantage over other vegetables because it has a shorter growth period, and inclement weather rarely results in complete crop loss (Bashaasha *et al.,* 1995). Processing the storage roots of *I. batatas* enhances accessibility and reduces post-harvest waste (Arutselvan *et al*., 2023).

I. batatas is a fundamental source of carbohydrates, energy, and essential phytonutrients (Mohanraj and Sivasankar, 2014). It is expected to play an important role in addressing malnutrition (Naskar *et al*., 2008). Due to their unique nutritional value and processing methods, the National Aeronautics and Space Administration (NASA) has selected *I. batatas* as a potential food item for astronauts on space missions (Arutselvan *et al*., 2023). In addition to its storage roots, *I. batatas* vines and foliage are essential sources of vitamins, proteins and starch (Chakrabarti *et al*., 2014).

I. batatas is grown in South Africa when dry conditions are not suitable for cereals (Motsa *et al*., 2015). *I. batatas* can adapt to diverse climatic and soil conditions, which has positioned it as a resilient and essential component of agricultural systems (Solomon, 1999; Mwanga *et al.,* 2021). Hence, *I. batatas* is considered as a food security crop providing a high yield in terms of edible energy per unit area over a short period of time.

Cultivation practices for *I. batatas* vary depending on local agro-climatic conditions. It typically thrives in well-drained sandy or loamy soils with pH levels of 5.5-6.5 and moderate rainfall. It is propagated primarily through vine cuttings or tubers and has a relatively short growth cycle of 3-5 months. Its yield is influenced by factors such as variety, soil fertility, and management practices, with average global yields ranging from 15-25 tons per hectare (Department of Agriculture, 2021).

Genetic diversity in *I. batatas* is remarkable, with significant accession diversity observed in landraces and wild relatives, which serve as valuable genetic resources for breeding programs (Abed *et al*., 2023; Mahaman Mourtala *et al*., 2023). The genetic diversity of *I. batatas* is more significant than that of potato, which is increasingly utilized by plant breeders searching for potential crop improvement (Woolfe, 1992). *I. batatas* accessions can share identical physical traits but differ genetically; conversely, genetically identical clones can exhibit varying physical characteristics (Lebot, 2009). Some accessions of *I. batatas* germplasm in Sri Lanka have been previously evaluated (Premathilake, 1999; Vilochani *et al.,* 2011). These diverse accessions can be utilized to enhance traits such as yield, resistance to pests and diseases, drought tolerance, and nutritional quality.

Storage root enlargement (sink) and leaf canopy photosynthetic efficiency (source) are both important for crop productivity and are primarily influenced by environmental factors (Ghosh *et al.,*1988; Palaniswami & Peter, 2008). However, genotypic variation and ecological conditions determine the source potential and the sink capacity (Ravi & Indira, 1998).

In Sri Lanka*, I. batatas* can be cultivated throughout the year under different growing conditions (rice fallow land, open highland, river valley basins, homestead, partial shade) in all the agroecological zones (De Silva and Premathilake, 1995). However, the extent of shortening the vegetative phase in *I. batatas* varies based on genetic factors and the local environment (Lamaro, 2020). Different *I. batatas* varieties respond differently to poly sack cultivation (Ndwamato *et al.,* 2022).

Poly sack cultivation has been shown to be optimal for urban gardens (Pearson *et al*., 2010) and is particularly well-suited for infertile soils as well as drought-prone or flood-prone regions (Tixier & De Bon, 2006). Generally, poly sack cultivation of vegetables ensures four meals per week for a family (Pascal & Mwende, 2009). Compared to traditional field methods, poly sack cultivation requires less space and labour (Essilfie *et al*., 2016), watering (Dubbeling & Massonneau, 2014), and weeding is more convenient (Badgely *et al*., 2007). Utilizing poly sack cultivation has the potential to expedite the vegetative phase of *I. batatas*, as the controlled environment provided by poly sacks can create optimal growing conditions leading to faster growth and development of the plants. This acceleration could reduce the time taken for the plants to mature, providing an advantage over weevil and other soil-borne pests (Johnson & Gurr, 2016).

While *I. batatas* has been discussed in various contexts, there is a noticeable gap in the existing literature on comparative yield analysis of different indigenous *I. batatas* accessions in Sri Lanka.

This study aims to understand the genetic diversity of *I. batatas* accessions and their yield potential to introduce planting materials and simultaneously conserve the genetic diversity of *I. batatas*. Further, adopting poly sack cultivation excludes many barriers faced in the field. Additionally, a broader range of individuals, including rural and urban, young and adult, can contribute to sustainable agricultural practices. This study evaluated the yield performance of twenty-two indigenous and improved *I. batatas* genotypes under poly sack cultivation, with implications for urban agricultural practices.

The primary objectives of this study were to assess the diversity among indigenous accessions of *I. batatas* compared to improved varieties, identify the traits influencing yield, and evaluate the yield performance of each genotype under poly sack cultivation.

MATERIALS AND METHODS

The indigenous accessions (denoted by *TJ* numbers) and improved *I. batatas* varieties (denoted by names) were used in this study. These accessions were *TJ1, TJ2, TJ4, TJ5, TJ7, TJ8, TJ9, TJ10, TJ11, TJ12, TJ14, TJ15, TJ16, TJ17, TJ18, TJ19, TJ20,* and the improved varieties *Ama, HORDI white, Ranabima, Shanthi, and Wariyapola-red.* Indigenous accessions were collected from different locations in Southern Sri Lanka namely *Tangalle, Kataragama, Tissamaharama, Sooriyawewa, Ambalantota, Weligama, Devinuwara (Dondra), Akuressa, Kamburugamuwa, Pitabeddara, Hikkaduwa, Ahangama, Karapitiya, Ambalangoda,* and *Yakkalamulla.* The experiment comparing field and poly sack cultivation techniques was conducted at the Agriculture Research Station in Thelijjawila, Matara. Sri Lanka (6°01'04.5"N, 80°30'15.5"E).

Crop establishment in poly sacks and the field

The cuttings were collected from the field-established germplasm collection. In the field, 0.3 m elevated ridges were prepared using the same soil mixtures that were used for the poly sacks, and the cuttings were planted with a spacing of 60 x 20 cm. Poly sacks with dimensions of 55 x 35 cm were used for the experiment. The sacks were filled with a potting mixture of topsoil, cow dung, and partially burnt paddy husk in a 1:1:1 ratio. The total weight of the potting mixture in each sack was 10 kg. Each cutting measuring approximately 25 cm in length was planted in the poly sacks (Supplementary Figure 1). Poly sacks were maintained under the same environmental conditions as the field experiment. The experiment was conducted from August to December in 2022 and 2023. Data were collected at the maturity stage, identified by yellowing of the lower leaves and latex exudation from damaged stems. Irrigation was practiced daily during the first week. The plants were established with the onset of the southwest monsoon, and weed management was done manually. Fertilization was carried out by following the recommendations provided by the Department of Agriculture, Sri Lanka: basal dressing was applied two weeks after planting (urea 60 kg/ha, TSP 120 kg/ha, and MOP 120 kg/ha), and top dressing was applied six weeks after planting (urea 60 kg/ha, and MOP 60 kg/ha). Fertilizer was applied based on the calculated per-plant requirement, considering the polybag and field area.

Experimental design and data collection

The experiment was conducted in poly sacks using a randomized complete block design with three replicates, each replicate consisting of ten poly sacks. The experiment was repeated in two seasons. All qualitative and quantitative data were collected according to the descriptors for *I. batatas* (Huaman, 1999), developed by the joint contribution of the International Potato Center (CIP), the Asian Vegetable Research and Development Center (AVRDC), and the International Board for Plant Genetic Resources (IBPGR).

Parameters evaluated for characterization of *I. batatas*

The qualitative canopy characteristics included the general outline of the leaf lamina, lobe prominence, central lobe shape, petiole pigmentation, abaxial vein pigmentation, and foliage colour. Qualitative storage root characteristics included shape variations of the root, skin colour, and predominant and secondary flesh colour. The vegetative characteristics studied were mature leaf length (cm), internodal length (cm), number of leaves per plant, number of branches per plant, vine length (cm), yield per plant (kg), cortex thickness (mm), length of storage roots (cm), and width of storage roots (cm). Quantitative data were analyzed using SPSS software (SPSS Inc., 2012).

Data analysis

Analysis of variance (ANOVA) was performed to assess the overall significance of differences among genotypes for various traits. Duncan's multiple range test (DMRT) was applied as a post-hoc test to identify significant differences in yield among genotypes. Principal component analysis (PCA) was used to reduce dimensionality and identify key traits contributing to variability among genotypes. Cluster analysis, using Ward's linkage method, grouped genotypes based on similarities in observed traits. Correlation analysis was conducted to explore relationships between yield and other agronomic traits.

RESULTS AND DISCUSSION

Diversity of indigenous *I. batatas* accessions

There was significant diversity among the examined genotypes of *I. batatas* in various qualitative and quantitative characteristics. The leaf outline shape showed distinct variation: triangular, cordate, hastate or lobed outline (Supplementary Figure 2).

Most genotypes, except *TJ9, TJ17,* and *TJ18*, had green mature leaves (Supplementary Figure 2). *TJ9, TJ17*, and *TJ18* showed yellow-green leaves, green leaves with purple veins on the upper surface, and both leaf surfaces purple, respectively. Both mature and immature leaves were green in *TJ1, TJ8, TJ20, Shanthi*, and *HORDI-white*. Other accessions were green and purple. Interestingly in the group of accessions with purple pigments on leaves, *TJ18* mature leaves were purple, but immature leaves were green while *TJ4, TJ5, TJ7, TJ9-TJ15, TJ16, TJ19, TJ20, Ama, Ranabima,* and *Wariyapola-red*, showed various purple pigmentation patterns in the immature leaves (Table 1, Supplementary Figure 3).

TJ1, TJ2, TJ4, TJ19, Ama, HORDI-white and *Wariyapola-red* had green petioles while other accessions exhibited purple pigments. Among genotypes with green

Table 1: Qualitative leaf characteristics of *I. batatas* genotypes

Genotype	General outline	Lobe prominence	Central lobe shape	Petiole pigmentation	Abaxial vein pigmentation	Foliage color	
						Mature	Immature
TJ 1	Cordate	NLL	TO	G	G	G	G
TJ2	Cordate	NLL	TO	G	G	G	GG
TJ4	Lobed	S	TR	G	G	G	GPE
TJ5	Lobed	S	TR	GPBE	PSMRB	G	GPE
TJ7	Cordate	NLL	TO	GPNL	PSMRB	G	GPE
TJ8	Lobed	VD	OB	GPNL	PSMRB	G	G
TJ9	Triangular	VS	TR	GPS	AVPP	YG	GG
TJ10	Cordate	NLL	SE	GPNL	G	G	PBS
TJ11	Lobed	M	L	GPNL	PSMRB	G	MP
TJ12	Lobed	D	L	GPNL	PSMRB	G	PBS
TJ14	Hastate	S	SE	GPSTP	PSSV	G	PBS
TJ15	Cordate	VS	SC	GPNL	G	G	GG
TJ16	Cordate	NLL	TO	GPNL	PSMRB	G	GPVUS
TJ17	Lobed	D	SE	MP	AVMP	GPVUS	G
TJ18	Lobed	D	L	MP	MP	PBS	G
TJ19	Cordate	NLL	TR	G	G	G	PBS
TJ20	Lobed	M	SE	GPBE	AVMP	G	G
Ama	Lobed	D	L	G	G	G	SP
HORDI white	Lobed	M	E	G	G	G	G
Ranabima	Triangular	VS	TR	GPS	G	G	GPNL
Shanthi	Cordate	NLL	TO	GPNL	GPNL	G	G
Wariyapola-red	Lobed	VS	TO	G	G	G	GPE

NLL: no lateral lobes, S: slight, VS: very slight, M: moderate, D: deep, VD: very deep, TO: toothed, TR: triangular, SE: semi-elliptic, L: lanceolate, SC: semi-circular, OB: oblanceolate, E: elliptic, G: green, PSMRB: a purple spot in main rib base, AVPP: all veins partially purple, PSSV: purple spots in several veins, AVMP: all veins mostly purple, MP: mostly purple, GPNL: green with purple near leaf, YG: yellow-green, GPVUS: green with purple veins on the upper surface, PBS: purple both surfaces, GG: greyish green, GPE: green with purple edge, MP: mostly purple, GPNL: green with purple near leaf base, SP: slightly purple, GPS: green with purple stripes, GPSTP: green with purple spot throughout petiole, GPBE: green with purple at both ends.

petioles, observed leaf margins were cordate in *TJ1, TJ2* and *TJ19* while *TJ4, Ama, HORDI-white* and *Wariyapola-red* were lobed (Supplementary Figure 2). In the group of purple pigmented petioles, *TJ5, TJ8, TJ11, TJ12, TJ17, TJ18* and *TJ20* leaf lamina were lobed whereas *TJ9* and *Ranabima* were triangular. Hastate leaf lamina was observed only in *TJ14* while *TJ7, TJ10, TJ15, TJ16* and *Shanthi* leaf lamina were cordate (Table 1, Supplementary Figure 2).

The leaf lobes showed different degrees of prominence: very slight, slight, moderate, deep, or very deep. The central lobes exhibited seven different shapes (Table 1). The number of lobes in the accessions exhibited a range of variation, transitioning from 3, 5 to 7 lobes. Rahajeng *et al.,* (2018) have also documented the presence of 3, 5, and 7 lobes in the *I. batatas* accessions they studied. The diversity in purple pigmentation in the leaves, veins, and petiole, along with the shape of leaf lamina and the features of the main lobe, can be used to distinguish the studied *I. batatas* genotypes. *TJ17* and *TJ18* accessions possess ornamental value due to their vibrant canopy colors (Supplementary Figure 3).

The qualitative attributes of the storage roots of the *I. batatas* genotypes were assessed in terms of storage root shape, size variations, and skin and flesh colors (Table 2). Storage roots did not emerge in the *TJ17* and *TJ18* accessions.

The flesh of the storage root displayed colors, ranging from white, cream, pale orange, intermediate orange to vividly pigmented with anthocyanin (Supplementary Figure 4). Mau *et al.,* (2022) reported six accessions with anthocyanin pigmentation in the flesh and nine with anthocyanin pigmentation in the twigs. The tuber skin exhibited diverse colours: brownish orange, cream, dark purple, pink, purple-red, and white (Supplementary Figure 4). This diversity highlights the inherent breeding potential for various combinations of traits in offspring.

Table 2: Qualitative storage root characteristics of *I. batatas* genotypes

Genotype	Shape	Shape variation	Size variation	Skin color	Flesh color (predominant)	Flesh color (Secondary)	Dispersion of secondary flesh color
TJ 1	Obovate	Slight	Slight	BO	White	Absent	A
TJ2	Long elliptic	Uniform	Slight	C	White	Cream	S
TJ4	Obovate	Slight	Slight	PR	Pale Yellow	Cream	BRC
TJ5	Round elliptic	Slight	Slight	PR	Cream	Absent	A
TJ7	Ovate	Moderate	Slight	BO	Pale orange	Cream	S
TJ8	Elliptic	Uniform	Slight	C	White	Cream	NRC
TJ9	Long elliptic	Slight	Moderate	PR	White	Absent	A
TJ10	Long curved	Slight	Moderate	DP	SPWA	Dark purple	S
TJ11	Round elliptic	Slight	Slight	C	I. Orange	Cream	S
TJ12	Long curved	Slight	Moderate	C	White	Cream	BRC
TJ14	Long irregular	Slight	Slight	DP	SPWA	White	NRF
TJ15	Long elliptic	Slight	Moderate	C	White	Cream	S
TJ16	Long irregular	Slight	Slight	DP	SPWA	White	S
TJ19	Elliptic	Slight	Slight	DP	SPWA	Dark purple	BRF
TJ20	Round	Moderate	Moderate	P	Cream	White	S
Ama	Long elliptic	Slight	Slight	PR	Pale orange	Cream	BRC
HORDI-white	Oblong	Slight	Moderate	W	White	Cream	NRC
Ranabima	Long elliptic	Slight	Moderate	PR	Cream	Pink	BRF
Shanthi	Elliptic	Slight	Slight	C	White	Absent	A
Wariyapola-red	Long curved	Slight	Moderate	PR	White	Absent	A

BO: brownish orange, C: cream, DP: dark purple, P: pink, PR: purple-red, W: white, SPWA: strongly pigmented with anthocyanins, I. Orange: intermediate orange, A: absent, S: scattered, BRC: broad ring in the cortex, NRF: narrow ring in the flesh, BRF: broad ring in the flesh, NRC: narrow ring in the cortex.

I. batatas accessions and improved varieties can be distinguished according to the following key based on qualitative leaf and tuber characteristics.

Ipomoea batatas

1.Canopy has green leaves with purple pigmentation
  2. Leaf margin is laterally lobed
    3. Petiole is pigmented with purple and green; some are moderately purple
      4. Leaf abaxial veins are mostly purple
        5. Mature leaves are purple pigmented ………………………………………………………..…*TJ18*
        5'. Mature leaves are not purple pigmented; they're green
          6. Produce storage root…………………………………………………………………..…..*TJ20*
          6'. Do not produce storage root…………………………………………………..……...*TJ17*
      4'. Leaf abaxial veins are not mostly purple; exhibits a green mixed with purple colour
        7. Leaf margin is moderate to deeply lobed
          8. Storage root is carotene pigmented; orange flesh………………………………………….*TJ12*
          8'. Storage root is not carotene pigmented; white flesh…………………………………………*TJ11*
        7'. Leaf margin is not deeply lobed; slightly lobed
          9. Leaf veins have purple spots
            10. Storage root is strongly pigmented with anthocyanins; purple pigmented flesh………..*TJ14*
            10'. Storage root is not pigmented with anthocyanins; white or cream color flesh
              11.Mature leaf exhibits green with yellow pigmentation…………………………………*TJ9*
              11'. Mature leaf has no yellow mixed green; only green colour…………………………..*TJ5*
          9'. Leaf veins have no purple spots; green pigmented veins………………………………*Ranabima*
    3'. Petiole is green pigmented; no purple
      12. Storage root flesh is carotene pigmented……………………………………………………….*Ama*
      12'. Storage root flesh is not carotene pigmented; white or cream flesh
        13. Flesh exhibits a secondary colour: cream………………………………………………...*TJ4*
        13'. Flesh has no secondary color distribution………………………………………*Wariyapola-red*
  2'. Leaf margin is not laterally lobed; only central lobe is present
    14. Petiole is green with purple pigmented
      15. Purple spot in main rib base
        14. Storage root is strongly pigmented with anthocyanins; purple flesh……………………….*TJ16*
        14'. Storage root is not pigmented with anthocyanins; orange colour…………………………...*TJ7*
      15'. No purple spots in main rib base
        15. storage root is anthocyanin pigmented; purple flesh……………………………………..*TJ15*
        15'. Storage root is not anthocyanin pigmented; white flesh……………………………………*TJ10*
    14'. Petiole is green without purple pigmentation
      16. Tooth shaped central lobe…………………………………………………………………….*TJ2*
      16'. Triangular shaped central lobe……………………………………………………………..*TJ19*
1'. Canopy has green foliage; no purple pigmentation
  15. Leaf margin is laterally lobed
    16. Deeply lobed; 7 lobes…………………………………...…………………………………………*TJ8*
    16'. Moderately lobed; 3 lobes …………………………………….……………………… *HORDI-white*
  15'. Leaf margin is not laterally lobed; central lobe tooth shaped
    17. Storage root skin is carotene pigmented; brownish orange skin……………………………………..*TJ1*
    17'. Storage root skin is not carotene pigmented; white skin…………………………….……….*Shanthi*

Quantitative canopy and storage root characteristics showed statistically significant differences among all the studied genotypes (Table 3). Variety *Ama* recorded the longest main vine length (140 cm) and internodal length (8.89 cm). *Wariyapola-red* had the shortest vine internodal length (2.16 cm) and the thickest root cortex (3.6 cm). In a previous study with sixty-two *I. batatas* accessions, vine length ranged from 83.08 to 283.80 cm, with an average of 178.65 cm (Rahajeng & Rahayuningsih, 2017). The same study reported that the number of branches per plant ranged from 0.80 to 1.60. In this study, the improved variety *'HORDI-white'* and indigenous accession *TJ11* had the highest number of branches per plant (4 branches). The improved variety, *Shanthi*, had the lowest values for vine diameter, mature leaf length, petiole length, and storage root width (Table 3).

Table 3: DMRT grouping of all the evaluated morphological traits in *I. batatas* genotypes cultivated in poly sacks

Accession name	MVL (cm)	NLPP	NBPP	VIL (cm)	VD (mm)	MLL (cm)	PL (cm)	SRL (cm)	SRW (cm)	RCT (mm)	TY (kg)
TJ1	92.72^{bc}	101.06^{ab}	2.72^{i}	5.69^{b}	4.33^{efgh}	13.61^{a}	16.21^{bc}	10.03^{cdef}	4.45^{cde}	2.08^{cd}	2.41^{b}
TJ2	46.44^{g}	65.56^{cdefg}	2.94^{ghi}	2.40^{i}	4.27^{fgh}	9.25h^{i}	12.22^{cdef}	14.08^{abc}	4.63^{bcd}	2.08^{cd}	1.81^{d}
TJ4	65.61^{cdefg}	84.50^{bc}	3.33^{cdefgh}	5.46^{bc}	4.11^{gh}	9.91^{ghi}	11.04^{def}	9.30^{ef}	3.73^{efg}	2.65^{bcd}	0.16^{k}
TJ5	97.72^{b}	39.94^{fgh}	3.67^{abcde}	4.04^{def}	5.22^{bc}	13.43^{a}	15.88^{bcd}	12.47^{bcdef}	4.87^{bcd}	1.68^{d}	0.40^{j}
TJ7	47.50^{g}	44.44^{efgh}	3.00^{ghi}	3.22^{gh}	4.56^{defg}	13.82^{a}	14.55^{bcde}	9.67^{def}	6.37^{a}	3.57^{a}	1.24^{f}
TJ8	65.06^{cdefg}	52.67^{defgh}	3.56^{bcdef}	3.36^{fgh}	4.05^{h}	12.15^{bcd}	13.63^{cdef}	10.45^{cdef}	4.00^{def}	2.6^{bcd}	0.60^{i}
TJ9	41.67^{g}	72.00^{cde}	3.06^{fghi}	2.23^{i}	4.27^{fgh}	11.52^{cde}	12.07^{cdef}	12.53^{bcdef}	3.08^{g}	1.85^{cd}	1.15^{f}
TJ10	57.06^{efg}	42.33^{efgh}	2.89^{hi}	2.19^{i}	4.61^{def}	10.04^{fghi}	12.89^{cdef}	15.83^{ab}	3.38^{fg}	1.60^{c}	1.41^{e}
TJ11	54.39^{fg}	114.50^{a}	4.11^{a}	3.51^{efgh}	3.50^{h}	10.82^{efg}	11.52^{cdef}	8.67^{f}	3.63^{efg}	1.63^{d}	2.42^{b}
TJ12	81.11^{bcdef}	54.00^{cdefgh}	3.17^{efghi}	4.26^{de}	3.94^{h}	10.41^{efgh}	10.04^{ef}	13.22^{abcde}	3.40^{fg}	2.03^{cd}	0.84^{h}
TJ14	84.67b^{cde}	47.50^{efgh}	3.56^{bcdef}	4.76^{cd}	4.61^{def}	12.58^{abc}	11.43^{cdef}	12.05^{bcdef}	3.03^{g}	2.38^{bcd}	1.45^{e}
TJ15	40.17^{g}	68.56^{cdef}	4.06^{ab}	2.83^{hi}	5.27^{ab}	9.76^{ghi}	10.41^{ef}	16.67^{a}	4.92^{bcd}	2.40^{bcd}	1.02^{g}
TJ16	53.61^{fg}	60.94^{cdefgh}	3.78^{abc}	3.94^{efg}	4.78^{de}	13.46^{a}	15.66^{bcd}	12.32^{bcdef}	4.08^{def}	1.75^{cd}	0.40^{j}
TJ17	48.39^{g}	31.11^{h}	2.89^{hi}	2.30^{i}	5.67^{a}	12.86^{ab}	21.89^{a}				0.00^{l}
TJ18	87.22^{bcd}	35.72^{gh}	3.78^{abc}	5.14^{bc}	4.17^{fgh}	13.41^{ab}	21.37^{a}				0.00^{l}
TJ19	78.33^{bcdef}	34.06^{gh}	3.83^{abc}	3.76^{efg}	4.83^{cd}	12.52^{abc}	15.83^{bcd}	14.9^{ab}	5.08^{bc}	3.13^{ab}	2.93^{a}
TJ20	65.22^{cdefg}	37.67^{fgh}	3.72^{abcde}	3.38^{fgh}	4.56^{defg}	10.24^{fgh}	12.23^{cdef}	10.27^{cdef}	6.45^{a}	2.75^{abc}	2.27^{c}
Ama	140.00^{a}	37.83^{fgh}	3.22^{defghi}	8.89^{a}	3.94^{h}	10.93^{efg}	13.06^{cdef}	11.92^{bcdef}	5.25^{bc}	2.75^{abc}	0.40^{j}
HORDI-white	48.22^{g}	79.78^{bcd}	4.11^{a}	3.27^{gh}	4.83^{cd}	12.85^{ab}	13.01^{cdef}	13.00^{abcde}	5.55^{ab}	2.5^{bcd}	0.84^{h}
Ranabima	138.11^{a}	55.44^{cdefgh}	3.83^{abc}	5.71^{b}	4.05^{h}	10.82^{efg}	18.60^{ab}	9.12^{ef}	2.75^{gh}	2.08^{cd}	0.45^{j}
Shanthi	91.89^{bc}	35.72^{gh}	3.44^{cdefg}	5.01^{bc}	2.00^{j}	8.92^{i}	8.72^{f}	13.55^{abcd}	2.10^{h}	1.78^{cd}	0.12^{kl}
Wariyapola-red	60.28^{defg}	63.94^{cdefg}	3.72^{abcde}	2.16^{i}	4.94^{bcd}	11.29^{def}	13.14^{cdef}	15.35^{ab}	4.6^{bcd}	3.6^{a}	0.37^{j}

MVL: main vine length, NLPP: number of leaves per plant, NBPP: number of branches per plant, VIL: vine internode length, VD: vine diameter, MLL: mature leaf length, PL: petiole length, SRL: storage root length, SRW: storage root width, RCT: root cortex thickness, TY: total yield

TJ15 recorded the longest storage root length at 16.67 cm, while *TJ11* had the shortest at 8.67 cm. *TJ20* and *TJ7* demonstrated the maximum storage root width, measuring 6.45 cm and 6.37 cm respectively. The broadest vine diameter measuring 5.67 mm was observed in *TJ17*. Hence, *TJ17* and *TJ20* accessions have a significant breeding potential for future research studies. Stem thickness has been identified as a favourable trait for extensive storage in *I. batatas* by Ndwamato *et al., (*2022). Furthermore, Raemaekers (2001) confirmed that genetic and environmental factors control vegetative growth, including the vine diameter of *I. batatas*.

Principal component (PC) analysis resulted in four principal components with more than one Eigenvalue. PC1 was significantly influenced by vine diameter, storage root width, root cortex thickness, the best four storage root yield, and total yield (Table 4).

Table 4: Component matrix of *I. batatas* genotypes.

Quantitative characteristics	Component			
	1	2	3	4
Main vine length (cm)	-0.556	0.659	-0.388	0.097
Number of leave per plant	-0.081	-0.066	0.77	-0.38
Number of branches per plant	0.126	-0.116	0.378	0.051
Vine internode length (cm)	-0.467	0.65	-0.384	-0.164
Vine diameter (mm)	0.741	0.146	0.262	0.45
Mature leaf length (cm)	0.362	0.683	0.406	0.142
Petiole length (cm)	0.15	0.778	0.297	0.266
Storage root length (cm)	0.182	-0.586	-0.243	0.673
Storage root width (cm)	0.905	0.208	-0.141	-0.244
Root cortex thickness (mm)	0.663	0.206	-0.343	-0.029
Best four storage root yield (kg)	0.89	0.196	-0.238	-0.062
Total yield (kg)	0.702	-0.265	-0.221	-0.445

PC2 showed significant contributions from main vine length, petiole length, and mature leaf length, while PC3 was primarily constructed by the number of leaves per plant. The storage root length was the most prominent contributor to PC4. The four principal components described 76.5% of the total variance, while the principal components 1, 2, and 3 explained 32%, 21%, and 14%, respectively.

In a previous study, nineteen phenotypic traits elucidated 77.8% of the variance (Placide *et al.,* 2015). Rahajeng *et al.,* (2023) reported 76.3% of the variance described by seven principal components. Premathilake (1999) and Vilochani (2011) have reported the diversity in different *I. batatas* accessions in prior studies. In the present study Cluster I consisted of ten genotypes, showing similarities in mature leaf length, petiole length, and vine diameter. Cluster II and Cluster III consisted of three and two genotypes, respectively. The number of leaves per plant, vine diameter, and storage root width were common characteristics found in Cluster II, while main vine length, number of branches per plant, mature leaf length, storage root length and root cortex thickness were common in Cluster III. Cluster IV consisted of genotypes with similarities in main vine length, number of branches per plant, vine internode length, and storage root length.

Character correlation is important in plant breeding (Kuswantoro, 2017) to determine the plant's architecture for optimal yield. However, none of the vegetative characteristics were significantly and positively correlated with storage root yield. The total yield was only correlated with storage root width (Table 5). Previous studies have also suggested that total yield was associated with root length and width (Lesatri *et al.,* 2021). However, in this study, total yield was not correlated with storage root length (r=-0.011), but with storage root width (r=0.716) (Table 5). Additionally, the storage root width was correlated with root cortex thickness (r=0.606). The width and cortex thickness of storage roots are important for determining yield as they represent different aspects of the anatomy of *I. batatas*'s related to nutrient storage and physiological regulation (Ravi *et al.,* 2014). The cortex of sweet potatoes refer to the tissue surrounding the vascular system within the storage root playing a vital role in nutrient storage and transportation. A thicker cortex indicates greater storage capacity for nutrients and carbohydrates leading to higher yields and improved quality.

Total yield was significantly and negatively correlated with the main vine length (r=-0.495). Excessive vegetative growth in *I. batatas* reduces tuber storage root yield due to resource competition. When the plant invests too much energy in producing and maintaining above-ground foliage, resources are diverted from tuber development resulting in smaller and fewer storage roots. Consistent with this, Sakaigaichi *et al.,* (2023) observed a substantial increase in yield in compact genotypes of *I. batatas*. However, high heritability estimates for the main vine length of *I. batatas,* suggest challenges in achieving compact genotypes through breeding programmes (Narayan *et al*., 2022). Additionally, excessive foliage can cause shading limiting the sunlight reaching the lower parts of the plant and further inhibiting tuber growth.

Main vine length showed a significant positive correlation with vine internodal length (r = 0.864) and petiole length (r= 0.346) of *I. batatas*. This aligns with findings by Abed *et al.,* (2023), who observed similar correlations with correlation coefficients of r = 0.83 for internodal length and r = 0.67 for petiole length. The number of leaves per plant did not positively correlate

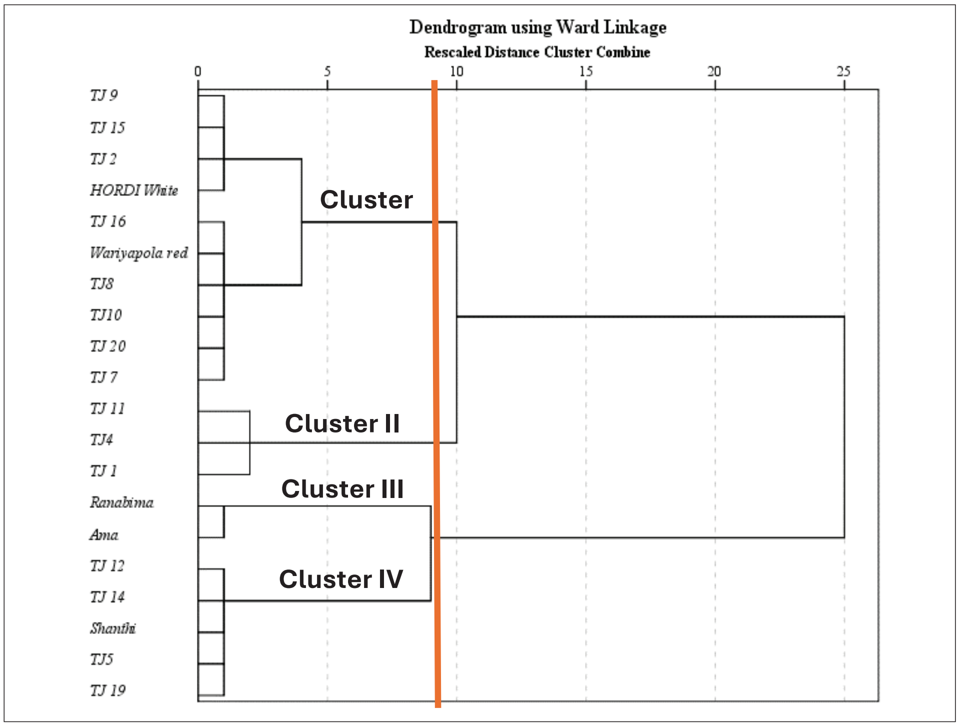

Figure 4: Hierarchical agglomerative clustering among the accessions, a dendrogram of genetic distance made using PCA data employing the Ward criterion method.

The 2D scatter plot diagram showed moderate dispersion in all four quadrants. A tight cluster was visible, suggesting a strong relationship between some accessions. The improved varieties *Ama* and Shanthi had more dispersion, indicating a distant relationship. *TJ11, TJ19, TJ20*, and *TJ7* were also isolated from other genotypes. Among them, *TJ11, TJ19,* and *TJ20* were high-yielding accessions.

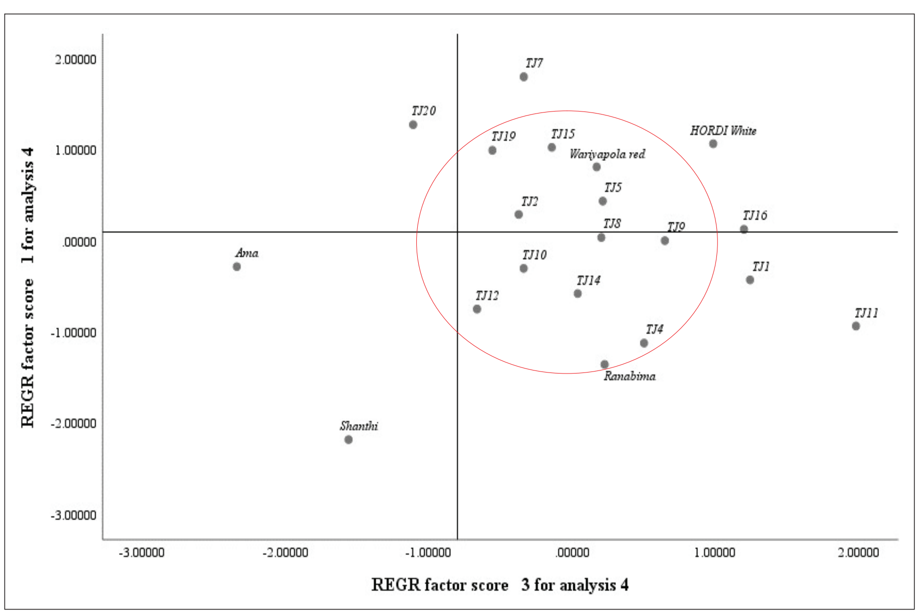

Figure 5: 2D scatter plot for *I. batatas* accessions.

with storage root characteristics (r=-0.146). According to Widaryanto & Saitama (2017), the leaf area index of *I. batatas* was negatively correlated with the storage root yield. Proper pruning or management of vegetative growth can redirect resources to storage root production and enhance *I. batatas* yield. Panggabean *et al.,* (2014) have recommended shoot pruning to increase yield in *I. batatas*. Future research should focus on improving storage root enlargement in *I. batatas* through shoot pruning by adjusting the number of leaves and the leaf area index (LAI). This can be accomplished by improving translocation efficiency to the storage roots, as indicated by positive changes in correlation values (Ndwamato *et al.,* 2022).

Table 5: Correlation matrix of *I. batatas* genotypes

Traits	MVL (cm)	NLPP	NBPP	VIL (cm)	VD (mm)	MLL (cm)	PL (cm)	SRL (cm)	SRW (cm)	RCT (mm)	BFSRW (kg)
NLPP	-.294										
NBPP	-.129	.155									
VIL	**.864**	-.132	-.159								
VD	-.311	-.003	.173	-.362							
MLL	-.004	.115	.017	.089	.469						
PL	**.346**	.015	-.008	.176	.410	.617					
SRL	-.314	-.282	.013	-.378	.290	-.352	-.360				
SRW	-.307	-.061	.033	-.148	**.572**	.345	.189	-.042			
RCT	-.114	-.250	.040	-.087	.314	.244	.105	.053	**.606**		
BFSRW	-.270	-.157	-.008	-.133	**.566**	.355	.144	.132	**.944**	**.684**	
TY	**-.495**	**-.146**	.052	-.346	.315	**-.135**	-.183	-.011	**.716**	.350	**.559**

MVL: main vine length, NLPP: number of leaves per plant, NBPP: number of branches per plant, VIL: vine internode length, VD: vine diameter, MLL: mature leaf length, PL: petiole length, SRL: storage root length, SRW: storage root width, RCT: root cortex thickness, BFSRY: best four storage root weight, TY: total yield

Duncan's multiple range test (DMRT) revealed significant yield differences across different genotypes in poly sack cultivation (Table 3).

Genotypes *TJ19, TJ11, TJ1,* and *TJ20* produced better yields under poly sack cultivation with 2.93 kg, 2.43 kg, 2.42 kg and 2.27 kg, respectively. The improved varieties *Ranabima, Shanthi, Wariyapola-red* and an indigenous accession *TJ1* yielded less than 1 kg per plant in poly sack cultivation; *TJ17* and *TJ18* recorded no yield under poly sack cultivation (Table 3), while *TJ16* was delayed in maturation in poly sacks. Maturation of *I. batatas* genotypes differs based on their genotype and environmental factors during cultivation (Bararyenya *et al.,* 2020). The production of storage root in *I. batatas* is influenced by sink-source; the sinking rate varies among varieties, resulting in yield variability. Some varieties prioritize shoot development, whereas others focus on enhancing root production (Ndwamato *et al*., 2022). The yield variations among the genotypes occur due to genetic composition and environmental conditions (Ngailo *et al*., 2013).

Generally, *I. batatas* has three growth phases based on dry matter partitioning. Shoot growth dominates during the first phase followed by the second phase, which involves consistent allocation between development of shoot and tubers (Ravi & Saravanan, 2012). High soil moisture extends the duration of total dry matter production, reducing the dry matter allocated for tubers and diverting it toward shoot growth (Satapathy *et al*., 2005). The location where the study was carried out received prolonged rainfall that posed a potential challenge by saturating the soil. This excessive moisture limits the availability of oxygen in the root zone. Storage roots require sufficient O_2 for their initiation and development, and excess soil moisture induces anaerobiosis, leading to decreased tuber production (Goswamy *et al*., 1995). Surplus soil moisture results in a decrease in the number of tubers and size while causing an increase in the weight of fresh shoots. This is likely attributable to sink capacity reduction, obstructing photosynthate translocation to storage roots (Ravi & Saravanan, 2012). Additionally, excessive water can reduce proper aeration due to soil compression caused by the expansion of storage roots.

The observed variations in yield highlight the potential for optimizing agricultural practices to maximize overall crop yield.

CONCLUSIONS

The findings of this research report on the diversity of the studied *I. batatas* genotypes and their varying yield potential. *TJ19* yielded the highest per plant yeild (2.93 kg) followed by *TJ11 and TJ1*, which recorded the second highest (2.42 kg), and *TJ20*, which recorded the third highest (2.27 kg) per plant yield. This indicates that these accessions are the most suitable for poly sack cultivation. The four principal components exceeding Eigenvalue one collectively explained 76.55% of the overall variance. Storage root attributes and vine diameter influenced PC1. Four clusters were distinguished by utilizing Ward linkage in hierarchical agglomerative clustering at a cluster distance of ten. The most robust storage roots belonged to Cluster II. The 2D scatter plot diagram illustrated moderate variation among the accessions. Vine diameter was the only vegetative factor that influenced the yield of *I. batatas* ($r > 0.3$), while main vine length and number of leaves negatively affected the total yield ($r > -0.3$). Therefore, understanding the determinants of *I. batatas* yield provides practical guidance for breeding programs. Accessions *TJ19, TJ11, TJ1* and *TJ20* were the best-yielding genotypes for poly sack cultivation. Further studies must be carried out to control the vegetative growth of them to maximize storage root yield. Additionally, more *I. batatas* accessions need to be collected and evaluated to exploit the advantage of *I. batatas* germplasm and yield performances must be evaluated under different agro-ecological zone.

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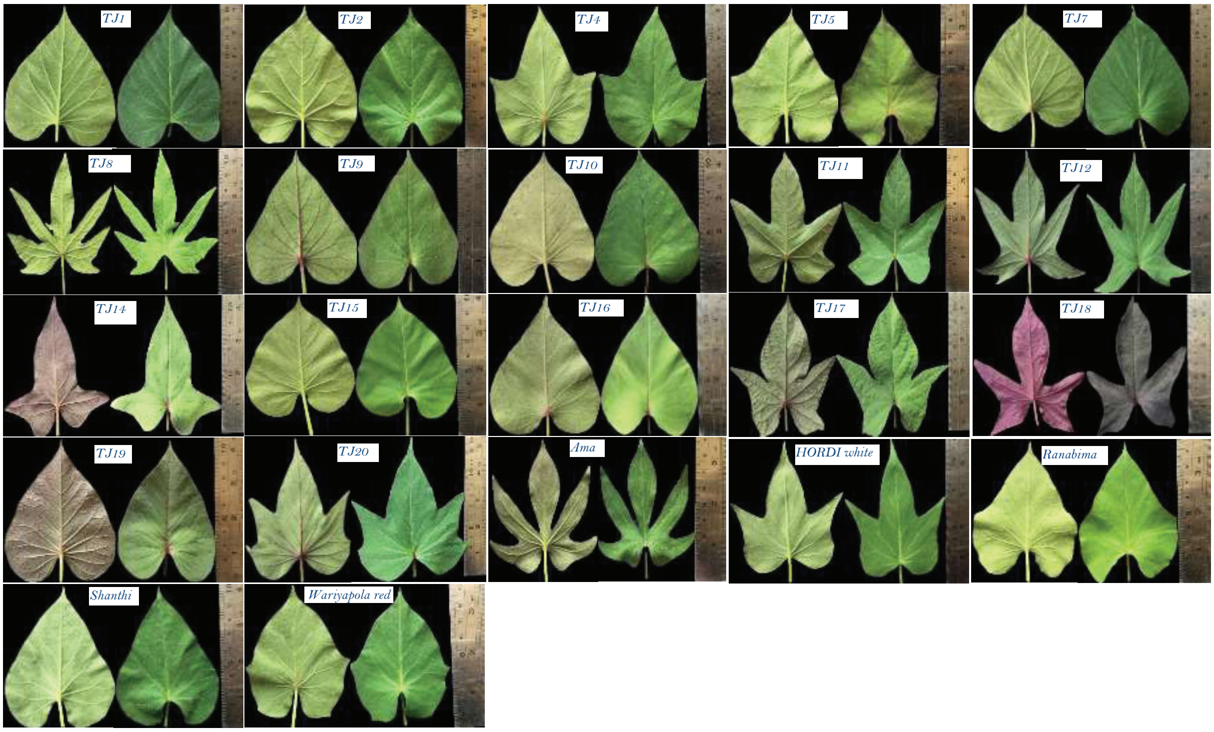
Supplementary Figures

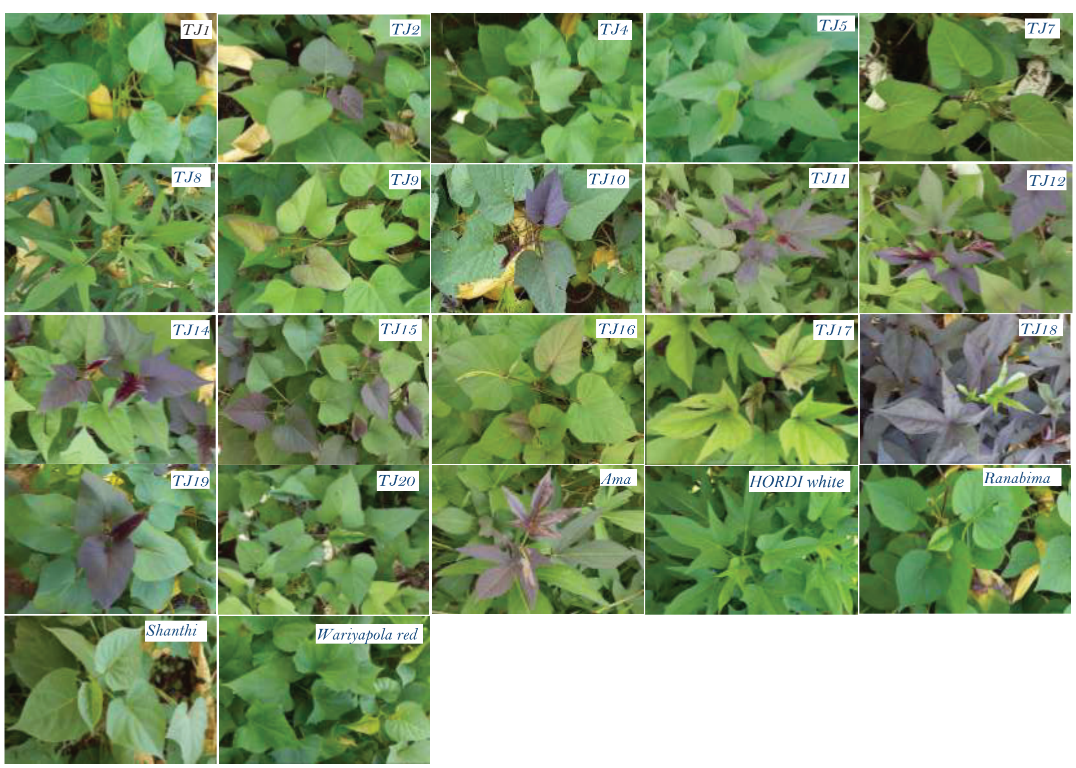
(1A)

(1B)

Supplementary Figure 1: (1A) Field established sweet potato genotypes.
(1B) Poly sack cultivated sweet potato genotypes collected for the photograph.



Supplementary Figure 2: Leaf characteristics of studied *I. batatas* genotypes



Supplementary Figure 3: Canopy appearance of studied *I. batatas* genotypes

Supplementary Figure 4: Qualitative storage root characteristics of *I. batatas* genotypes