Heliyon 9 (2023) e18203

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Yield performance and trait correlation of BARI released sweet potato varieties studied under several districts of Bangladesh

Zakaria Alam [a,*,1], Sanjida Akter [b,1], Md Anwar Hossain Khan [a,2], Md Shamshul Alam [a,2], Shamima Sultana [c,1], Sohela Akhter [a,3], Md Mizanur Rahman [d,1], Md Mazadul Islam [a,1]

[a] *Tuber Crops Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh*
[b] *Entomology Division, Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh*
[c] *Regional Agricultural Research Station, BARI, Cumilla, Bangladesh*
[d] *On Farm Research Division, BARI, Sherpur, Bangladesh*

A R T I C L E I N F O

Keywords:
Sweet potato
BARI Mistialu
Marketable storage root yield
Yield
Correlation

A B S T R A C T

A study was carried out in five sweet potato growing regions of Bangladesh, each characterized by suitable agro-ecologies, in order to demonstrate the most favorable varietal performance and trait correlations. A completely randomized block design with three replications was used to compare the varietal performance of BARI (Bangladesh Agricultural Research Institute) released sweet potato varieties (viz. BARI Mistialu-9, BARI Mistialu-10, BARI Mistialu-12, BARI Mistialu-15 and BARI Mistialu-17). During the 2021-22 cropping season, sweet potato varieties were tested in five districts of Bangladesh, namely Gazipur, Bogura, Jamalpur, Jashore, and Chattogram. The findings revealed that the BARI Mistialu-12 variety exhibited remarkable attributes, including a high marketable storage root yield of 39.88 t/ha. Additionally, it demonstrated exceptional performance in various yield components such as vine length, average storage root weight, and dry weight of the root. Furthermore, a positive correlation was observed between several traits and yield, as well as yield-attributing characteristics. This correlation suggests that enhancing these traits could potentially contribute to an overall increase in the storage root yield of sweet potatoes.

1. Introduction

Sweet potatoes (Ipomoea batatas L.) have diverse applications that vary across different regions. They serve as valuable food commodities, can be utilized as animal fodder, and are even processed into a wide array of products such as breads, breakfast items, french fries, syrup, starch, and beverages [1]. Sweet potatoes rank as the sixth most widely consumed carbohydrate-rich food on a global scale, and China stands as the leading producer, with an annual production of 71 million tons [2]. Among all natural food crops cultivated in sub-Saharan Africa, sweet potatoes offer the highest edible energy per hectare per day. They are also a significant crop in

* Corresponding author.
E-mail address: za.jakir@yahoo.com (Z. Alam).
[1] Scientific Officer.
[2] Senior Scientific Officer.
[3] Director.

https://doi.org/10.1016/j.heliyon.2023.e18203
Received 24 February 2023; Received in revised form 6 July 2023; Accepted 11 July 2023
Available online 12 July 2023

various regions of Uganda, Malawi, and Rwanda [3]. In China, Vietnam, and Papua New Guinea, it is crucial to utilize both the vines and roots of sweet potatoes for pig feeding [4]. The cultivation of sweet potatoes in tropical America dates back to before 6000 BCE. During pre-Columbian times, it naturally spread to regions such as Polynesia, Hawaii, and New Zealand. In the 16th century, the Spanish introduced the crop to the Philippines, from where it further dispersed to neighboring islands and the Asian mainland. By 1594, sweet potatoes were documented in south China, and during the reign of the Qing Empire (1644–1912), efforts were made to promote its cultivation to alleviate drought. Additionally, Portuguese seafarers played a significant role in introducing the crop to parts of Southeast Asia, Africa, and western Mediterranean Europe [5,6].

In South Asia, particularly in India, Bangladesh, Sri Lanka, and the Maldives (riverbanks), sweet potatoes, locally known as Mistialu, are predominantly produced and consumed by impoverished communities [1,4]. Vitamin A deficiency is a significant concern in rural and slum areas of Bangladesh, with approximately 8% of toddlers experiencing daily vision loss due to this deficiency, leading to night blindness [7]. To address this issue, nutritional education plays a crucial role in promoting the consumption of orange-fleshed sweet potatoes, which are a valuable source of vitamin A. Over the years, sweet potato production in Bangladesh has shown positive growth. From 2018–19 to 2020–21, there was a notable increase of 15.70% in overall sweet potato production, reaching 279,800 metric tons (MT), while the country's land area dedicated to sweet potato cultivation expanded by 13.20% (from 23, 024 to 26,528 ha) [8]. This growth can be attributed to the introduction and adoption of improved sweet potato cultivars provided by the Bangladesh Agricultural Research Institute (BARI), the implementation of enhanced cultivation practices, and increased awareness among farmers [9]. Furthermore, sweet potato cultivation has proven to be a significant source of income for farmers in Bangladesh, contributing to their overall revenue [9]. In Bangladesh, the average root yield of sweet potatoes currently stands at around 10.50 tons per hectare, despite estimates suggesting a potential or achievable yield of up to 40 tons per hectare [8,9]. There are several strategies that can be explored to bridge this yield gap and potentially enhance sweet potato production [9]. Given the increasing demand for food to support a growing population, it becomes crucial to explore the untapped potential of Bangladesh's vast land resources for expanded sweet potato cultivation. In many developing countries, farming and staple crops serve as the primary sources of food for rural families. Sweet potatoes, known for their resilient characteristics, hold significant value as a crop for ensuring food security worldwide. The key growth traits of sweet potatoes include their adaptability to various soil types, thriving in both rich and poor sandy soils, their ability to grow throughout the year in tropical regions, their high root yield per hectare, their tolerance to salt and drought, and their resistance to several pests and diseases. These traits enable sweet potato plants to generate income while providing sustenance for people.

Despite having access to various agricultural technologies, Bangladesh is actively promoting the cultivation of crops like sweet potatoes in underserved areas. One of the main factors contributing to this initiative is a lack of understanding regarding farmers' nutritional needs and their access to high-yielding cultivars. As awareness grows among health-conscious individuals in other countries about the remarkable nutritional value of sweet potatoes, the demand for this crop is on the rise [10]. Therefore, sweet potatoes play a crucial role in ensuring food security in Bangladesh. The Tuber Crops Research Centre (TCRC) of the Bangladesh Agricultural Research Institute (BARI) has developed seventeen different varieties of sweet potatoes, with additional promising lines currently being suggested and developed. This study aimed to assess the performance of the sweet potato varieties released by BARI and explore the correlations between yield and yield-related traits.

2. Materials and methods

2.1. Description of the study area

The study was carried out during the 2021-22 growing season in five districts of Bangladesh: Gazipur, Bogura, Jamalpur,

Table 1
Physico-chemical characteristics of the soil in the research area (Source: Regional Research Station of BARI).

Soil properties	Value				
	Location				
	Gazipur	Bogura	Jamalpur	Jashore	Chattogram
Texture	Silty clay loam	Sandy loam	Sandy loam	Sandy loam	Silty loam
pH (H_2O)	5.73	6.23	6.48	6.61	4.58
Organic matter (%)	1.75	3.50	1.42	2.50	1.25
Total nitrogen (%)	0.05	0.10	0.08	0.20	0.08
Available phosphorus (ppm)	35	28	12.85	0.41	24
Exchangeable Ca (meq/100 g)	1.30	0.16	2.50	0.12	1.05
Exchangeable K (meq/100 g)	0.71	0.60	0.09	0.25	0.54
Exchangeable Mg (meq/100 g)	0.39	0.10	0.08	0.21	0.25
Exchangeable Na (meq/100 g)	1.22	1.52	0.31	0.52	1.01
Exchangeable Fe (meq/100 g)	31	28	35.42	25	19
Exchangeable Mn (meq/100 g)	7.2	6.32	15.23	5.25	4.25
Exchangeable Cu (meq/100 g)	0.51	0.23	1.02	0.56	0.42
Exchangeable Zn (meq/100 g)	0.80	0.74	1.53	1.20	0.57
Exchangeable acidity (mg/kg)	0.35	0.19	0.10	0.14	0.24

Chattogram, and Jashore. These districts were selected as they represent favorable growing regions for sweet potatoes and possess suitable agro-ecological conditions. The research site is located in Bangladesh, between latitudes 23.6850° N and longitudes 90.3563° E, with an elevation ranging from 10 m (Coastal South) to 105 m (North) above sea level. Table 1 provides an overview of some of the physico-chemical characteristics of the soil in the study area. Additionally, Table 2 and Table 3 present the monthly average temperature and rainfall data, respectively, recorded in the research area.

2.2. Experimental material and design

Five well-known sweet potato varieties from the TCRC, BARI, Gazipur, were employed in the experiment: BARI Mistialu-9, BARI Mistialu-10, BARI Mistialu-12, BARI Mistialu-15, and BARI Mistialu-17. The varieties are fully described in Table 4. A randomized complete block design (RCBD) with three replications was employed in the study.

2.3. Experimental techniques

The research site underwent ploughing until a fine tilth was achieved. Subsequently, ridges were manually constructed with conventional hoes, following the farming practices prevalent in the experimental area. The entire field was divided into three blocks, each containing five plots, resulting in a total of fifteen plots. Each unit plot measured 3 m by 3 m and consisted of five rows with ten plants per row. The suggested plant spacing was 30 cm, while the row spacing was 60 cm. Gaps of 1 m and 1.5 m were maintained between plots and blocks, respectively. For planting, vine cuttings of 30 cm in length were used, with two-thirds of their length covered with soil. One vine was placed in each ridge hole, and any dead vines were replaced through replanting one week after the initial planting.

Hand hoeing was carried out to lay out the experimental plots, ensuring the area remained free from weeds throughout the growing season. Starting from the second month after planting, the soil around the plants was earthed up three times at monthly intervals to protect the storage roots from exposure. The crop received various nutrient inputs, including urea, TSP, MOP, gypsum, zinc sulphate, magnesium sulphate and boric acid in quantities of 260, 150, 250, 75, 12, 100, and 10 kg/ha, respectively. Additionally, 10 t/ha of cow dung was applied. During the final stage of land preparation, the full dose of TSP, gypsum, zinc sulphate, magnesium sulphate, boric acid, and cow dung was applied, along with half the dosage of urea and MOP. Forty days after vine planting, the remaining urea and MOP were topically applied, followed by watering and earthing up [11].

To achieve the objectives of the study and minimize the influence of external factors on the treatments, disease incidence and insect pest occurrence were carefully monitored throughout the growing season. Notably, no instances of disease incidence or insect pest infestation were observed during the course of the trial. Harvesting took place at 130 days after planting, with the sweet potato roots being dug out using hoes and carefully hand-plucked once the leaves had turned yellow. The vines and leaves were also trimmed off during this process.

2.4. Data collection

Data were gathered from two net-harvestable rows of 10 randomly chosen plants from each plot for each variety.

2.4.1. Mean vine length (cm): The lengths of the vines of the ten selected plants were measured, and the average value was calculated for each plant.

2.4.2. Storage root length (cm): The lengths of the mature storage roots of 10 randomly selected plants from each plot were averaged, and this average value was used as the basis for all further data analysis.

2.4.3. Storage root diameter (cm): The average size of the storage root diameter was calculated by taking an average of the grith at the center portion of the mature storage roots of 10 randomly chosen plants.

2.4.4. Average storage roots per plant: The average number of storage roots per plant was calculated by averaging the number of storage roots counted from the tested plants.

2.4.5. Average storage roots weight per plant (kg): The average weight of storage roots per plant was calculated by averaging the fresh weight of the storage roots of the plants in the sample.

2.4.6. Marketable storage root number per plant: Ten plants were sampled from each plot, and the marketable storage roots of those plants were tallied and divided by the number of plants sampled. Marketable roots were defined as storage roots that were free of any damage, un-infested by insect pests, and had a weight between 100 and 500g.

Table 2
Monthly average Temperature data of research area (Cropping season: 2021–22) (Source: Bangladesh Meteorological Department).

Months	Year	Temperature (^{0}C)				
		Gazipur	Bogura	Jamalpur	Chattogram	Jashore
November	2021	24.15	23.35	22.55	26.07	22.82
December		21.05	20.33	19.42	22.15	18.66
January	2022	19.61	17.53	18.06	20.74	17.63
February		21.25	19.42	19.11	22.05	19.70
March		28.12	27.04	25.77	27.15	26.53

Table 3
Monthly average Rainfall data of research area (Cropping season: 2021–22) (Source: Bangladesh Meteorological Department).

Months	Year	Rainfall (mm)				
		Gazipur	Bogura	Jamalpur	Chattogram	Jashore
November	2021	27	0	1	0	45
December		153	1	9	95	193
January	2022	12	17	9	1	7
February		20	40	15	11	38
March		14	0	0	0	0
Total (mm)		226	58	34	107	283

Table 4
Descriptions of five BARI released sweet potato varieties (Source: TCRC, BARI).

Genotype	Origin	Altitude (m)	Year of release	Stem color	Skin Color	Maturity days	Flesh colour	Yield (t/ha)
BARI Mistialu-9	Peru	1555	2008	Green	Red	120–130	Orange	25–30
BARI Mistialu-10	Bangladesh	10–105	2013	Green	Brown	120–130	Cream	30–35
BARI Mistialu-12	Peru	1555	2013	Green	Off white	120–130	Cream	35–40
BARI Mistialu-15	Peru	1555	2017	Green	Pink	120–130	Orange	35–40
BARI Mistialu-17	Indonesia	367	2021	Green	Purple	120–130	Purple	30–35

2.4.7. The number of non-marketable storage roots per plant: By sorting and counting the non-marketable storage roots of 10 sampled plants from each plot at maturity, and dividing this number by the total number of the sampled plants, the number of non-marketable storage roots per plant was calculated. Any storage roots that had been damaged, were infected with insects, and did not weigh between 100 and 500 g were non-marketable.

2.4.8. Marketable storage root yield (t/ha): This was estimated by dividing the average marketable storage root production of the sample plants by the density of the plants per hectare of land.

2.4.9. Non-marketable storage root yield (t/ha): This was computed by dividing the average yield of unsalable storage roots of the studied plants by the density of the plants per hectare of land.

2.4.10. Dry matter content (%): One hundred grams of fresh sweet potato from each plot was obtained, sliced, and immediately weighed. The samples were then kept in a well-ventilated room for five days before being dried in a laboratory oven for 24 h at 80 °C. The following formula was then used to determine the dry matter content (%) [12].

$$\text{Dry matter }(\%) = (\text{weight of sample (g) after drying} / \text{fresh sample weight (g)}) \times 100$$

2.5. Statistical analysis

The data were evaluated by analysis of variance (ANOVA) performed using R statistical analysis systems 4.2.0 [13]. The mean values of plant in response to applied treatments (Varieties and Locations) were compared using LSD tests at $p < 0.05$. A combined analysis over locations was used to provide the findings of the effect of varieties [14]. The Pearson correlation was tested to see the correlation between the traits. The correlation matrix presented the significant ($p < 0.05$) correlations determined by the Pearson correlation analysis.

Table 5
Average values of BARI released sweet potato varieties grown in five districts of Bangladesh.

Variety	VL (cm)	ARL (cm)	ARD (cm)	MRN	ARN	NMRY (t/ha)	ARW (kg)	DW (%)
BARI Mistialu-9	96.76^{b}	14.59^{b}	4.58^{b}	6.61^{a}	8.27^{a}	1.65^{b}	0.67^{ab}	21.66^{c}
BARI Mistialu-10	103.40^{b}	14.54^{b}	4.42^{b}	4.80^{c}	6.19^{c}	1.44^{b}	0.57^{b}	21.01^{c}
BARI Mistialu-12	124.13^{a}	15.02^{b}	4.27^{bc}	5.44^{bc}	6.73^{bc}	1.36^{b}	0.77^{a}	30.97^{a}
BARI Mistialu-15	102.25^{b}	16.90^{a}	5.20^{a}	5.96^{ab}	7.23^{b}	1.46^{b}	0.71^{a}	22.10^{c}
BARI Mistialu-17	98.22^{b}	13.86^{b}	3.94^{c}	5.30^{bc}	6.97^{bc}	8.79^{a}	0.67^{ab}	24.78^{b}
$LSD_{0.05}$	13.15	1.73	0.45	0.79	0.97	2.57	0.12	1.76
p-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CV (%)	12.36	11.40	9.95	13.92	13.48	86.12	17.20	7.20

Mean was calculated based on three replications of each treatment. Values in a column with different letter(s) are significantly different at $p < 0.05$ applying LSD test.
VL = vine length, ARL = average storage root length, ARD = average storage root diameter, MRN = marketable storage root number per plant, ARN = average storage root number per plant, NMRY = non-marketable storage root yield, ARW = average storage root weight per plant, DW = dry weight of storage root.

3. Results and discussions

3.1. Vine length

Significant variations were observed for both varieties and locations ($p < 0.001$) in terms of vine length, as shown in Table 5 and Table 6. Analysis revealed that the BARI Mistialu-12 variety exhibited the longest vines, measuring 124.13 cm, while the BARI Mistialu-9 variety had the shortest vines, measuring 96.76 cm. Among the five locations, Gazipur had the longest vines, measuring 119.11 cm, whereas Bogura displayed the shortest vines, measuring 89.47 cm. These findings align with the research conducted by Latif [15], who reported vine lengths ranging from 49.83 cm to 77.28 cm in the evaluation of four sweet potato varieties at 100 days after planting, with the highest length observed in the BARI Mistialu-12 variety. Gobena et al. [16] also noted significant variations in vine length among sweet potato varieties. Additionally, Nazrul [17] observed a considerable variation in vine length among five sweet potato varieties, ranging from 119 cm to 192.3 cm. These variations in vine length could be attributed to genetic diversity among the genotypes and their interaction with the environment.

3.2. Average storage root length

The investigation unveiled significant variations in the average storage root length among different varieties and locations, as indicated in Tables 5 and 6. Among the varieties, BARI Mistialu-15 displayed the longest average root length, measuring 16.90 cm, while BARI Mistialu-17 had the shortest average root length at 13.86 cm. BARI Mistialu-9, BARI Mistialu-10, and BARI Mistialu-12 exhibited statistically similar average root lengths of 14.59 cm, 14.54 cm, and 15.02 cm, respectively. In terms of locations, Jamalpur recorded the longest average root length at 16.27 cm, whereas Chattogram had the shortest average storage root length at 13.07 cm. These findings align with the research conducted by Shamil [18], who reported significant variations in root length among six studied varieties, ranging from 8.9 cm to 24.8 cm, highlighting the considerable variability across different genotypes. Rashid et al. [19], Rahman et al. [20], Rafique et al. [21], Reddy et al. [22], and Hayati et al. [23] all reported that the length of the storage roots varied across varieties. According to Rahman et al. [20], the genotype BARI SP-7, also known as BARI Mistialu-7, produced the longest storage roots, measuring 10.80 cm. It was closely followed by JSP-3 with 9.67 cm, JSP-1 with 9.53 cm, and JSP-7 with 3.81 cm. The study indicated that there were variations in both genetic and growth traits among the genotypes. Additionally, Mohammed [24] conducted a study on eight different sweet potato varieties and found significant variations among them. These variations were attributed to the genotypic diversity present among the varieties.

3.3. Average storage root diameter

Both the varieties and locations had a significant impact ($p < 0.01$) on the average storage root diameter of sweet potatoes, as shown in Tables 5 and 6. Our research findings revealed that BARI Mistialu-15 exhibited the largest root diameter, measuring 5.20 cm. This diameter was statistically similar to the root diameters of BARI Mistialu-9 (4.58 cm) and BARI Mistialu-10 (4.42 cm). On the other hand, BARI Mistialu-17 had the smallest root diameter, measuring 3.94 cm. Regarding the effect of location on root diameter, sweet potatoes harvested from Jamalpur had the largest diameter at 4.99 cm, which was statistically similar to the root diameters of Chattogram (4.87 cm) and Bogura (4.65 cm). Conversely, the smallest root diameter was observed in sweet potatoes harvested from Gazipur (3.77 cm), followed by Jashore (4.14 cm). It is important to note that there is significant variation in storage root diameter among different sweet potato varieties [25,26]. According to Hossain et al. [27], sweet potato genotypes exhibited substantial differences in terms of storage root diameter. Numerous domestic and international sources have reported on the variability of sweet potato storage root diameter [20–23]. These variations can be attributed to the genetic characteristics of the plant, soil types, soil fertility, cultivation methods, and environmental conditions.

Table 6
Locational average values of BARI released sweet potato varieties.

Location	VL (cm)	ARL (cm)	ARD (cm)	MRN	ARN	NMRY (t/ha)	ARW (kg)	DW (%)
Gazipur	119.11^{a}	15.53^{ab}	3.77^{b}	5.20^{b}	6.51^{bc}	1.79	0.59^{b}	24.06
Bogura	89.47^{c}	15.80^{ab}	4.65^{a}	6.14^{ab}	6.95^{b}	2.93	0.71^{ab}	24.54
Jamalpur	98.21^{bc}	16.27^{a}	4.99^{a}	7.25^{a}	9.12^{a}	3.64	0.77^{a}	25.21
Chattogram	113.44^{ab}	13.07^{c}	4.87^{a}	3.67^{c}	4.63^{c}	3.93	0.73^{ab}	23.17
Jashore	104.53^{abc}	14.25^{bc}	4.14^{b}	5.84^{ab}	8.19^{ab}	2.41	0.59^{b}	23.56
$LSD_{0.05}$	18.70	1.72	0.46	1.43	2.03	2.27	0.17	2.23
p-value	0.001	0.001	0.0001	0.0001	0.001	ns	0.01	ns
CV (%)	17.57	11.31	10.17	25.06	28.36	76.04	24.08	9.13

Mean was calculated based on three replications of each treatment. Values in a column with different letter(s) are significantly different at $p < 0.05$ applying LSD test.
VL = vine length, ARL = average storage root length, ARD = average storage root diameter, MRN = marketable storage root number per plant, ARN = average storage root number per plant, NMRY = non-marketable storage root yield, ARW = average storage root weight per plant, DW = dry weight of storage root., ns = non-significant.

3.4. Average storage root number per plant, marketable storage root number per plant and average storage root weight per plant

Significant differences ($p < 0.01$) were observed both among varieties and locations for the parameters mentioned (Tables 5 and 6). BARI Mistialu-9 exhibited the highest average marketable root number per plant (6.61), while BARI Mistialu-10 had the lowest (4.80). Among the locations, the highest average marketable root number per plant was observed in Jamalpur (7.25), while the lowest was in Chattogram (3.67). The average root number per plant was highest in BARI Mistialu-9 (8.27) and lowest in BARI Mistialu-10 (6.19). Similarly, the average root number per plant was highest in Jamalpur (9.12) and lowest in Chattogram (4.63). Increasing the number of storage roots per plant contributes to higher total sweet potato production. Therefore, BARI Mistialu-12 achieved the highest root weight per plant (0.77 kg), which was statistically similar to BARI Mistialu-15 (0.71 kg). On the other hand, BARI Mistialu-10, which had the fewest root number per plant overall, also had the lowest root weight per plant (0.57 kg). The maximum root weight per plant was found in Jamalpur (0.77 kg), which was statistically similar to Chattogram (0.73 kg) and Bogura (0.71 kg), followed by Gazipur and Jashore (0.59 kg). Vimala et al. [28] observed variations in storage root weight per plant among sweet potato clones, ranging from 0.17 to 1.3 kg/plant. Mohammed [24] also reported variation in the average number of roots among the varieties studied. Latif [15] found a significant variation in the number of roots per plant. These variations in characteristics may be attributed to the genetic diversity among the genotypes.

3.5. Non-marketable storage root yield

Significant variations ($p < 0.0001$) were observed in the yield of non-marketable storage roots among the different varieties used in the experiment (Table 5). However, there was no significant variation in non-marketable root yield among the different locations (Table 6). BARI Mistialu-17 had the highest production of non-marketable storage roots (8.79 t/ha), while BARI Mistialu-12 had the lowest (1.36 t/ha). BARI Mistialu-9 (1.56 t/ha), BARI Mistialu-10 (1.44 t/ha), and BARI Mistialu-15 (1.46 t/ha) had statistically similar non-marketable root yields, which were also relatively low. The non-marketable root yield varied between 1.79 t/ha and 3.93 t/ha across the different locations. According to Mohammed [24], there were significant differences in non-marketable storage root production among the eight sweet potato genotypes studied. In this study, several undesirable traits were identified in the sweet potato varieties that contributed to non-marketable yields, including storage roots smaller than 100 g or larger than 500 g, long tails, and deformed shapes. These traits were found to be less prevalent in certain areas, particularly in Jamalpur. It was observed that the BARI Mistialu-15 and BARI Mistialu-17 varieties had oversized storage roots exceeding 500 g. This could potentially be influenced by the soil structure and texture in the specific region. The majority of the root classes in BARI Mistialu-17 and BARI Mistialu-10 were non-marketable and were from tiny roots (less than 100 g). Despite the fact that storage roots weighing more than 500 g are regarded as non-marketable, the acceptance of such storage roots by customers is greater than that of storage roots that weigh less than 100 g.

3.6. Marketable storage root yield

Varieties had a significant impact on marketable storage root yield, as shown in Table 7. BARI Mistialu-12 exhibited the highest yield (39.88 t/ha), followed by BARI Mistialu-15 (36.60 t/ha), BARI Mistialu-9 (33.78 t/ha), and BARI Mistialu-10 (28.56 t/ha). This finding aligns with the research conducted by Sultana et al. [29], who also identified BARI Mistialu-12 as the superior genotype out of the 15 varieties tested in different environments. Conversely, BARI Mistialu-17 showed the lowest yield (25.98 t/ha).

Similar yield variations among sweet potato genotypes were reported by Karan and Sanli [30], Hossein et al. [27], and Rahman et al. [20]. The range of yield variation among genotypes can vary from 25.8 to 62.40 t/ha and from 2.04 t/ha to 48.80 t/ha. Nazrul [17] also observed a significantly higher yield of 40.63 t/ha among the five evaluated sweet potato varieties. In the combined analysis, significant variations in marketable storage root yield were also observed (Table 7). The highest yield (56.48 t/ha) was recorded in BARI Mistialu-10 when grown in conjunction with the Jamalpur location.

The development and yield of sweet potatoes are influenced by a combination of factors, including variety, soil quality, and

Table 7
Mean values of interaction effect (five varieties and five locations) on marketable storage root yield (MRY) of sweet potato.

Variety	MRY (t/ha)					
	Location					
	Gazipur	Bogura	Jamalpur	Chattogram	Jashore	Average
BARI Mistialu-9	27.59^{f-k}	35.06^{c-h}	33.77^{d-i}	39.14^{b-f}	33.33^{d-i}	33.78^{abc}
BARI Mistialu-10	22.78^{h-k}	29.65^{e-j}	56.48^{a}	14.82^{k}	19.07^{jk}	28.56^{bc}
BARI Mistialu-12	37.96^{b-g}	47.61^{abc}	22.84^{h-k}	49.05^{ab}	41.94^{b-e}	39.88^{a}
BARI Mistialu-15	34.63^{c-h}	35.37^{c-h}	44.91^{a-d}	44.60^{a-d}	23.52^{h-k}	36.60^{ab}
BARI Mistialu-17	25.93^{g-k}	28.88^{e-j}	29.48^{e-j}	24.49^{h-k}	21.11^{ijk}	25.98^{c}
$LSD_{0.05}$	13.21					8.12
p-value	0.0001					0.0001
CV (%)	24.29					24.29
Average	29.78	35.31	37.49	34.42	27.79	

Mean was calculated based on three replications of each treatment. Values in a column with different letter(s) are significantly different at $p < 0.05$ applying LSD test.

fertilizer use during cultivation [31]. Sen et al. [32] also emphasized that adopting appropriate cultural management strategies can contribute to the variation in yield among different genotypes. Among the five locations, Jamalpur had the highest mean yield (37.49 t/ha), which may be attributed to favorable soil and environmental conditions. On the other hand, Gazipur and Jashore exhibited lower yields, possibly due to higher total rainfall (226–283 mm) throughout the growing season. Lin et al. [33] demonstrated that sweet potatoes are sensitive to flooding stress, and midseason flooding can significantly reduce storage root yield by 57% [34].

The findings of this study are consistent with the results reported by Wonda et al. [35], which indicated that genotype, location, and genotype-by-location interaction all have a significant impact on sweet potato production. Mohammed [24] also observed considerable variation in marketable root yield among sweet potato varieties and suggested that this variation may be attributed to the genetic variability present in the genotypes under study. Similar variations in sweet potato genotypes were reported by Latif [15], Rahman et al. [20], Yohannes [36], Yooyongwech et al. [37], Gobena et al. [16], and Tesfaye et al. [38] in their adaptation studies conducted in various agro-ecologies. Rahman et al. [20] and Yooyongwech et al. [37] further concluded that the genetic composition of the plant influences the production potential of sweet potatoes, supporting the findings of this study. The variation in storage root yield of sweet potatoes may be attributed to genetic and environmental factors that affect root size, bulking rates, and the number of storage roots per plant.

3.7. Dry weight of storage root

There was a significant variation in root dry weight values among the different varieties tested, as indicated in Table 5. BARI Mistialu-12 had the highest dry weight of roots (30.97%), followed by BARI Mistialu-17 (24.78%). BARI Mistialu-10 (21.01%), BARI Mistialu-9 (21.66%), and BARI Mistialu-15 (22.10%) exhibited statistically similar values. The dry matter content of sweet potato genotypes' roots ranged from 26.8% to 33.5%, as reported by Teow et al. [39], while Kathabwalika et al. [40] reported a range of 26.8%–34.4%.

In terms of locations, there was no significant difference observed in the dry weight values of the roots, as shown in Table 6. According to Delowar and Hakim [41], the dry weight of storage roots can vary depending on how well each variety performs in a specific soil. Similar variations in dry matter content were also reported by Rahman et al. [20], Teow et al. [39], and Kathabwalika et al. [40].

3.8. Correlations among storage root yield and yield contributing traits: The correlation coefficients were calculated to assess the relationships between nine yield and yield-contributing traits, using data from five locations and five varieties, as presented in Table 8. The results indicated significant positive correlations ($p \leq 0.05$) between vine length and marketable root number ($r = 0.24$), marketable root weight ($r = 0.24$), and dry weight of storage root ($r = 0.26$). Average root number also showed a positive correlation ($p \leq 0.05$) with average root weight ($r = 0.29$). However, Amare et al. [42] reported no significant correlations among vine length, root number, root weight, and root yield. Average root length demonstrated a significant positive correlation ($p \leq 0.05$) with marketable root number ($r = 0.33$) and average root number ($r = 0.24$). According to Amare et al. [42], total storage root number exhibited a high positive correlation with storage root numbers and root yields. Conversely, Islam et al. [43] found a negative correlation between total root number and root length. Average root diameter exhibited a positive correlation with marketable root yield ($r = 0.29$) and average root weight ($r = 0.26$). The findings of Amare et al. [42], Sahu et al. [44], and Afuape et al. [45] support our results, indicating an extremely significant positive correlation between root yield, root weight, and root diameter. Furthermore, marketable root number showed positive correlations with marketable root yield ($r = 0.33$), average root number ($r = 0.96$), and average root weight ($r = 0.37$). Islam et al. [43] suggested that plants with smaller roots may be lighter, as they found a highly significant positive correlation between these traits. Marketable root yield exhibited a positive correlation with average root weight ($r = 0.92$) and a negative correlation with non-marketable root weight ($r = 0.32$). It is evident that non-marketable root weight can reduce the marketable root yield of sweet potatoes. Chipungo et al. [46] described a positive correlation between non-marketable root weight and non-marketable storage root yield, indicating that selecting either trait would similarly enhance non-marketable storage root yield. However, choosing to prioritize higher values for these traits may lead to undesired outcomes in one particular direction. Researchers [45,47–50] have found that storage root yield demonstrates positive and significant correlations with the number of storage roots per plant, weight of individual storage roots, bulking rate, and crop growth rate. This suggests that selecting and improving any of these traits will inevitably result in higher yields of storage roots in sweet potatoes. These correlation coefficients provide insights into the relationships between the evaluated characteristics, enabling us to identify the more and less relevant traits that need to be considered during breeding to maximize storage root yield in sweet potatoes.

4. Conclusion

At the phenotypic level, it was observed that storage root per plant, followed by root length and diameter, exerted a strong positive direct influence on storage root production per plant. These traits were identified as key factors influencing root yield in sweet potatoes. Therefore, selecting and improving these traits may lead to an overall increase in tuber yield.

The study revealed significant variations among the examined sweet potato varieties in terms of yield and yield-related traits. BARI Mistialu-17 and BARI Mistialu-10 showed lower productivity, while the BARI Mistialu-12 variety demonstrated high yield potential and superior performance in terms of productivity and yield components. Based on these findings, it can be recommended that the BARI Mistialu-12 variety is suitable for the studied locations as well as similar agro-ecologies. Farmers and communities involved in small-scale farming may benefit from adopting this variety.

Table 8
Linear correlation (Pearson coefficients) matrix between different agronomic attributes and marketable storage root yield of sweet potato varieties grown in five districts of Bangladesh.

	VL	ARL	ARD	MRN	MRY	ARN	ARW	NMRY	DW
VL	1								
ARL	−0.1^{ns}	1							
ARD	−0.2 ^{ns}	0.26*	1						
MRN	0.24*	0.33**	0.16^{ns}	1					
MRY	0.24*	0.2 ^{ns}	0.29*	0.33**	1				
ARN	−0.2 ^{ns}	0.24*	0.08^{ns}	0.96***	0.22^{ns}	1			
ARW	0.15^{ns}	0.12^{ns}	0.26*	0.37**	0.92***	0.29*	1		
NMRY	−0.23^{ns}	−0.19^{ns}	−0.15^{ns}	0.03^{ns}	−0.32**	0.09^{ns}	0.08^{ns}	1	
DW	0.26*	0.03^{ns}	−0.2^{ns}	−0.05^{ns}	0.14^{ns}	−0.06^{ns}	0.18^{ns}	0.12^{ns}	1

'- 'and '+' signs indicate negative and positive correlation between the traits studied in this experiment, respectively. *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$, ^{ns}: Non significant.
VL = vine length, ARL = average storage root length, ARD = average storage root diameter, MRN = marketable storage root number per plant, MRY = marketable storage root yield, ARN = average storage root number per plant, ARW = average storage root weight per plant, NMRY = non-marketable storage root yield, DW = dry weight of storage root.

Author contribution statement

Zakaria Alam: Performed the experiments and Wrote the paper.

Sanjida Akter and Sohela Akhter: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Conceived and designed the experiments.

Md Anwar Hossain Khan; Md Shamshul Alam; Shamima Sultana; Md Mizanur Rahman; Md Mazadul Islam: Performed the experiments.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

Acknowledgements

The authors are thankful to Bangladesh Agricultural Research Institute for providing planting materials for the study.

References

[1] G. Padmaja, Uses and nutritional data of sweet potato, The sweet potato (2009) 189–234, https://doi.org/10.1007/978-1-4020-9475-0_11.
[2] H. Van Chuyen, J.B. Eun, Nutritional quality of foods: sweet potato, Diet Quality: An Evidence-Based Approach 1 (2013) 247–256, https://doi.org/10.1007/978-1-4614-7339-8_19.
[3] J.W. Low, M. Arimond, N. Osman, B. Cunguara, F. Zano, D. Tschirley, A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique, The Journal of nutrition 137 (5) (2007) 1320–1327, https://doi.org/10.1093/jn/137.5.1320.
[4] D. Peters, Use of Sweet Potato in Pig Production in Asia: Agricultural and Socio-Economic Aspects, Pig News and Information, 2004, p. 10.
[5] P.J. O'Brien, The sweet potato: its origin and dispersal, Am. Anthropol. 74 (3) (1972) 342–365, https://doi.org/10.1525/aa.1972.74.3.02a00070.
[6] R. Jia, Weather shocks, sweet potatoes and peasant revolts in historical China, Econ. J. 124 (575) (2013) 92–118, https://doi.org/10.1111/ecoj.12037.
[7] Night Blindness, Banglapedia, the National Encyclopedia of Bangladesh, 2021, June 18. Retrieved from http://en.banglapedia.org/index.php?title=Night_Blindness.
[8] May, Yearbook of Agricultural Statistics-2021, Bangladesh Bureau of Statistics, 2022.
[9] Annual Research Report, Bangladesh Agricultural Research Institute, 2022.
[10] T. Johnson, N. Wilson, M.R. Worosz, D. Fields, J.K. Bond, Commodity Highlight: Sweet Potatoes, US Dept. Agr., Econ. Res. Serv. Pub., 2015. *No. VGS-355-SA1*.
[11] Annual Research Report, Bangladesh Agricultural Research Institute, 2020.
[12] J.K. Kwach, G.O. Odhiambo, M.M. Dida, S.T. Gichuki, Participatory consumer evaluation of twelve sweetpotato varieties in Kenya, Afr. J. Biotechnol. 9 (11) (2010) 1600–1609, https://doi.org/10.5897/AJB10.913.
[13] The R Project for Statistical Computing. (n.d.). Retrieved from https://www.r-project.org/. (R Foundation).
[14] K.A. Gomez, A.A. Gomez, Statistical Procedures for Agricultural Research, John wiley & sons, New York, 1984.

[15] T.M.A. Latif, Effect of Fertilizer on Growth and Yield of Sweet Potato at Farmer Field at Jamalpur, Bangladesh ([Doctoral Dissertation]. 1207, Department of Agricultural Botany, Sher-E-Bangla Agricultural University, Dhaka, 2020.

[16] T.L. Gobena, M.M. Asemie, T.B. Firisa, Evaluation of released sweet potato [Ipomoea batatas (L.) Lam] varieties for yield and yield-related attributes in Semen-Bench district of Bench-Sheko-Zone, South-Western Ethiopia, Heliyon 8 (10) (2022), e10950, https://doi.org/10.1016/j.heliyon.2022.e10950.

[17] M.I. Nazrul, On-farm evaluation of orange fleshed sweet potato varieties under acidic soil of north-east region in Bangladesh, Bangladesh Agronomy Journal 21 (2) (2018) 59–65, https://doi.org/10.3329/baj.v21i2.44493.

[18] A.S. Shamil, Evaluation of sweet potato (Ipomoea batatas (L) Lam) varieties at tepi, southwestern Ethiopia, World J. Agric. Soil Sci. 6 (4) (2021) 1–4, https://doi.org/10.33552/WJASS.2021.06.000643.

[19] M.M. Rashid, A.A. Mazumdar, S. Molla, Performance of exotic germplasm of sweet potato in Bangladesh, in: Proceedings of the 1st International Conference on Sweetpotato, Food and Health, Lima, Peru, 2002, pp. 291–295. July 26-29, 2001.

[20] H. Rahman, A.F.M. Islam, M. Maleque, R. Tabassum, Morpho-physiological evaluation of sweet potato (Ipomoea batatas L.) genotypes in acidic soil, Asian Journal of 7 (4) (2015) 267–276, https://doi.org/10.3923/ajcs.2015.267.276.

[21] F. Rafique, K. Fatema, M.H. Rahman, M.M. Hossain, Vegetative growth and yield performance of eight sweet potato genotypes, Bangladesh Hortic 1 (1&2) (2015) 103–110.

[22] R. Reddy, H. Soibam, V.S. Ayam, P. Panja, S. Mitra, Morphological characterization of sweet potato cultivars during growth, development and harvesting, Indian J. Agric. Res. 52 (1) (2018) 46–50, https://doi.org/10.18805/IJARe.A-4798.

[23] M. Hayati, E. Sabaruddin, A. Efendi, A. Anhar, Morphological characteristics and yields of several sweet potato (Ipomoea batatas L.) tubers, 1, in: IOP Conference Series. IOP Conference Series vol. 425, Earth and Environmental Science. IOP Publishing, 2020, 012055, https://doi.org/10.1088/1755-1315/425/1/012055.

[24] A. Mohammed, Evaluating the Performance of improved sweet potato (Ipomoea batatas) varieties at Shishir, Southern Ethiopia, Int. J. Res. Agric. For. 5 (6) (2018) 33–36.

[25] B. Mekonnen, S. Tulu, J. Nego, Evaluation of orange fleshed sweet potato (Ipomoea batatas L.) varieties for yield and yield contributing parameters in the humid tropics of Southwestern Ethiopia, J. Plant Sci. 10 (5) (2015) 191–199, https://doi.org/10.3923/jps.2015.191.199.

[26] D. Regassa, A. Shiferaw, W. Tigre, Sweet potato (Ipomia Batatus) varieties evaluation in Borana mid altitude, Sci. Res. 3 (5) (2015) 248, https://doi.org/10.11648/j.sr.20150305.12.

[27] M.M. Hossain, M.A. Rahim, H.N. Moutosi, L. Das, Evaluation of the growth, storage root yield, proximate composition, and mineral content of colored sweet potato genotypes, Journal of Agriculture and Food Research 8 (2022), 100289, https://doi.org/10.1016/j.jafr.2022.100289.

[28] B. Vimala, A. Sreekanth, B. Hariprakash, W.J. Gruneberg, Variation in morphological characters and storage root yield among exotic orange-fleshed sweet potato clones and their seedling population, J. Root 38 (1) (2012) 32–37.

[29] S. Sultana, H.C. Mohanta, Z. Alam, S. Naznin, S. Begum, Genotype and environment interaction of sweet potato varieties, Bangladesh J. Agric. Res. 44 (3) (2019) 501–512, https://doi.org/10.3329/bjar.v44i3.43481.

[30] Y.B. Karan, Ö.G. Şanli, The assessment of yield and quality traits of sweet potato (Ipomoea batatas L.) genotypes in middle Black Sea region, Turkey, PLoS One 16 (9) (2021), e0257703, https://doi.org/10.1371/journal.pone.0257703.

[31] L. Mao, R.N. Story, A.M. Hammond, J.K. Peterson, D.R. Labonte, Effect of nitrogen on resistance of sweet potato to sweetpotato weevil (Coleoptera: Curculionidae) and on storage root chemistry, Journal of economic entomology 94 (5) (2001) 1285–1291, https://doi.org/10.1603/0022-0493-94.5.1285.

[32] H. Sen, N. Roychoudhury, S.K. Mukhopadhyay, Performance of different sweet potato Ipomoea batatas entries in the alluvial soil of West Bengal, Environment and ecology. Kalyani 6 (2) (1988) 431–436.

[33] K.H.R. Lin, C.C. Tsou, S.Y. Hwang, L.F.O. Chen, H.F. Lo, Paclobutrazol pre-treatment enhanced flooding tolerance of sweet potato, J. Plant Physiol. 163 (7) (2006) 750–760, https://doi.org/10.1016/j.jplph.2005.07.008.

[34] W. Roberts, V. Russo, Time of flooding and cultivar affect sweetpotato yield, Hortscience 26 (12) (1991) 1473–1474, https://doi.org/10.21273/HORTSCI.26.12.1473.

[35] C.W. Wonda, L.G. Wilson, S. Arendell, F.L. Dickey, Genotype x Environmental interaction in sweet potato yield and quality factors, J. Am. Soc. Hortic. Sci. 112 (3) (2007) 579–583.

[36] G. Yohannes, Analysis of Genotype Environment Interaction and Trait Correlation in Orange –flashed Sweet Potato [Ipomoea Batata (L) Lam] Clones in Wollo, An Msc. Theis presented to the school of graduated studies of Harmaya University, 2007, p. 86.

[37] S. Yooyongwech, T. Samphumphuang, C. Theerawitaya, S. Cha-um, Physio-morphological responses of sweet potato [Ipomoea batatas (L.) Lam.] genotypes to water-deficit stress, Plant Omics 7 (5) (2014) 361–368.

[38] T. Tesfaye, T. Engida, T. Aseffa, A. Teshome, K. Asfawu, G. Yohannis, M. Daniel, Performance of medium and late maturing sweet potato germplasms in different agro ecologies of Ethiopia, in: Proceedings of the 14th Annual Conference of the Crop Science Society of Ethiopia, 2011, April, pp. 28–29.

[39] C.C. Teow, V.D. Truong, R.F. McFeeters, R.L. Thompson, K.V. Pecota, G.C. Yencho, Antioxidant activities, phenolic and β-carotene contents of sweet potato genotypes with varying flesh colours, Food Chem. 103 (3) (2007) 829–838, https://doi.org/10.1016/j.foodchem.2006.09.033.

[40] D.M. Kathabwalika, E.H.C. Chilembwe, V.M. Mwale, Evaluation of dry matter, starch and beta-carotene content in orange-fleshed sweet potato (Ipomoea batatas L.) genotypes tested in three agro-ecological zones of Malawi, Afr. J. Food Sci. 10 (11) (2016) 320–326, https://doi.org/10.5897/AJFS2016.1471.

[41] H.K. Delowar, M.A. Hakim, Effect of salinity levels on the morpho-physiological characteristics and yield attributes of sweetpotato genotypes, Int. J. Sci. Res. 10 (2014) 929–934.

[42] B. Amare, F. Abay, Y. Tsehaye, Interrelationships of sweet potato varieties and their characters for yield determination, Int. J. Sci. Basic Appl. Res. 37 (2) (2018) 261–274.

[43] J. Islam, M.Z. Haque, K. Majunder, M. Haque, F. Hossain, Growth and yield potential of nine selected genotypes of sweet potato, Pakistan J. Biol. Sci. 5 (5) (2002) 537–538, https://doi.org/10.3923/pjbs.2002.537.538.

[44] G.D. Sahu, J. Singh, N. Mehta, Correlation and path analysis in sweet potato, Environ. Ecol. 23 (2) (2005) 207.

[45] S.O. Afuape, P.I. Okocha, D. Njoku, Multivariate assessment of the agromorphological variability and yield components among sweet potato (Ipomoea batatas (L.) Lam) landraces, Afr. J. Plant Sci. 5 (2) (2011) 123–132.

[46] F.P. Chipungu, E.J. Issa, C.C. Moyo, I.R.M. Benesi, Field evaluation of introduced sweetpotato clones for yield and quality in Malawi, 6-10 November, 2000, in: Agricultural Technologies for Sustainable Development in Malawi, Proceedings of the first annual scientific conference held at the Malawi Institute of Management (MIM), Lilongwe, Malawi, 2001, pp. 179–183.

[47] E.U. Mbah, O. Eke-Okoro, Relationship between some growth parameters, dry matter content and yield of some sweet potato genotypes grown under rainfed weathered ultisols in the humid tropics, J. Agron. 14 (3) (2015) 121, https://doi.org/10.3923/ja.2015.121.129.

[48] O.M. Egbe, S.O. Afuape, J.A. Idoko, Performance of improved sweet potato (Ipomea batatas L.) varieties in Makurdi, Southern Guinea Savanna of Nigeria, Am. J. Exp. Agric. 2 (4) (2012) 573, https://doi.org/10.9734/AJEA/2012/1347.

[49] E. Tsegaye, E.D. Sastry, N. Dechassa, Correlation and path analysis in sweet potato and their implications for clonal selection, J. Agron. 5 (2006) 391–395, https://doi.org/10.3923/ja.2006.391.395.

[50] M.D. Hossain, M.G. Rabbani, M.L.R. Mollah, Genetic variability, correlation and path analysis of yield contributing characters in sweet potato (Ipomoea batatas Lam.), Pak. J. Sci. Ind. Res. 43 (2000) 314–318.