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PHYSICO-CHEMICAL AND ORGANOLEPTIC PROPERTIES OF SEEDED BANANA (*Musa acuminata*) GERMPLASM AVAILABLE IN SALT ECOSYSTEM

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Abstract

Coastal fruit production is increasingly threatened by soil and water salinity, necessitating resilient agricultural strategies. This study characterized the physico-chemical and organoleptic properties of four seeded bananas (*Musa acuminata*) germplasm (MB03, MB05, MB13, MB16) to identify promising cultivars for cultivation in salt-affected ecosystems. Physico-chemical analyses were conducted in the post-harvest laboratory of the Department of Horticulture between May to August, 2023. Laboratory experiments employed a Completely Randomized Design (CRD) to analyze variance and compare quantitative and qualitative parameters. In addition to conventional statistical analyses, Pearson's correlation, Principal Component Analysis (PCA), hierarchical cluster analysis, and farmer survey analysis were performed to evaluate trait relationships, germplasm variability, and farmer perceptions regarding seeded banana cultivation. Among the germplasms, MB16 exhibited the highest individual fruit weight (204.06 g), pulp weight (135.80 g), fingers/hand (14.60), bunch weight (21.05 kg), hand weight (2.70 kg), yield (49.46 t/ha), and TSS (18.0%). MB13 recorded the highest edible portion (75.74%), seed number (196.88), and pulp-to-peel ratio (3.63:1), but the lowest TSS (13.83%), whereas MB05 showed the lowest edible portion (62.58%), highest pH (6.43), carotene content (0.95 mg/g), shelf life (7.33 days), and hands/bunch (7.55). The highest titratable acidity (0.78%) and phenol content (15.75 mg GAE/g) were observed in MB03. In addition, MB13 exhibited the lowest weight loss percentage. Considering organoleptic evaluation, germplasm MB16 had attained the highest score in respect of almost all the parameter. The parameters of soft seed texture, high TSS content, good taste, yield and highly consumers preferences indicated that germplasm MB16 was found to be the best followed by MB03, MB13 and MB05 germplasm. Correlation analysis revealed a strong positive association between hand weight and peel weight ($r = 0.74$), while seed number showed a strong negative relationship with peel weight ($r = -0.84$). A strong negative correlation between hand weight and number of hands per bunch ($r = -0.90$) suggested possible assimilate competition during fruit development. PCA and cluster analyses further differentiated the germplasm based on fruit biomass and seed-related traits, with MB16 forming a distinct group associated with superior fruit quality and yield performance. Farmer survey analysis showed that 71.83% of respondents cultivated seeded banana for commercial purposes and 74.65% expressed interest in improved varieties. Artificial propagation was the predominant cultivation practice (84.51%), while Panama disease (27.46%) and Sigatoka disease (20.42%) were identified as major production constraints. Considering physico-chemical attributes, sensory acceptability, multivariate analyses, and farmer preference, MB16 was identified as the most promising seeded banana germplasm for cultivation and conservation in saline coastal ecosystems of Bangladesh.

Keywords: Seeded banana, Germplasm, Physical, Chemical, Organoleptic, PCA, Correlation

Introduction

Bananas (*Musa spp.*), a world-leading fruit crop, are cultivated worldwide from a diverse genetic base Anyasi et al. 2015). All modern cultivars originate from two wild ancestors, *Musa acuminata* and *Musa balbisiana*, and exhibit varying ploidy levels (Emaga et al. 2007). They offers various essential nutrients such as potassium, dietary fiber, and bioactive compounds as well as serve as staple crops in tropical and subtropical regions, (Anyasi et al. 2013; Awedem et al. 2015). Banana is tropical, highly nutritious, delicious and economically important fruit which is available throughout the year and is consumed in greater quantities than any other fruits (Rahman et al. 2019). Seeded bananas are botanically classified as *Musa balbisiana*. The conducted survey showed that old generation people like seeded banana the most than younger generation. Seeded banana has many nutraceutical properties such as it is traditionally used in curing diarrhea and dysentery. It also has antioxidant properties (Yusuf et al. 2009). These natural antioxidant properties play an important role in curing different disease such as cancer, diabetes, aging etc. (Turkoglu et al. 2010). Total phenolic content is present in ethyl acetate extract of banana seed (19.23 mg GAE/g extract) followed by the similar extract of banana pulp (15.78 mg GAE/g extract) and peel (11.23 mg GAE/g extract). In most of the cases the nutritional status of seeded banana blossoms is higher compared to cauliflower (Dan & Thaha, 2013).

However, enchantingly, certain indigenous banana races in these salt eco-system areas exhibit outstanding resilience, flourishing even without proper cultural practices. Aside from the commercially cultivated varieties, Bangladesh harbors numerous wild *Musa* species, crucial for maintaining the genetic diversity of the genus, found in forested areas and along riverbanks, serve as genetic reservoirs, offering potential traits for crop improvement and breeding programs aimed at enhancing disease resistance, yield, and nutritional quality (Uddin et al. 2018). Information on varietal characteristics of seeded banana in salt ecosystem are scarce. Although commercial banana production is growing, there is still a lack of research aimed at improving native varieties in Bangladesh, especially when it comes to the particular difficulties faced by areas afflicted by salt. By filling in these gaps, banana production might rise dramatically, benefiting both commercial growers and farmers.

In Bangladesh common types of bananas are table banana, green banana and seeded banana. Among these types, seeded banana is the most neglected species because of excessive seed content, hard texture of seed and lack of good taste. Excessive seed content act as negative effector which make people unwilling to choose this banana. As a result, the market price of seeded banana is quite low. In southern part of Bangladesh, there is a dominance of seeded banana generally grown in the homestead and road sides. People of Bangladesh like seeded banana with less seed, soft seed texture, good taste. So, there is a great scope to develop potential germplasm of quality seeded banana from the prevailing variability. In view of these facts, the study was performed in salt ecosystem to identify the potential germplasm of seeded banana and to collect and *ex situ* conservation of these germplasm.

Materials and Methods

Plant materials and experimental site

An initial survey identified sixteen distinct seeded banana germplasms in the study area, from which four viz. MB03, MB05, MB13, and MB16 were selected for detailed characterization due to their higher population frequency, indicating superior productivity, potential yield, and probable salt tolerance. The research was conducted in 'Kalapara' upazila, Patuakhali district, situated within Agroecological Zone (AEZ)-13 on the South-Central Coast of Bangladesh. The site's geographical coordinates are 21°48'-22°05'N latitude, 90°05'-90°20'E longitude, with an altitude of nine meters above sea level. Laboratory-based physico-chemical analyses were performed at the postharvest laboratory in the Department of Horticulture, PSTU.

Assessment of physical properties of selected seeded banana

Fully matured fruits were gradually collected to calculate the mean weight. The weight was taken in gram with a balance sensitive to 10 g. The number of seeds were counted manually from ripe fruits and average value was taken. Hardness of seed was measured by different scoring (1.0= Seed is very soft and mixable quality is very good; 1.5= Seed is medium soft and mixable quality is good; 2.0= Seed is medium hard and mixable quality is bad and 2.5= Seed is hard and mixable quality is very bad).

From fully ripe fruits seeds were separated, washed thoroughly with distilled water and the adjacent water was absorbed with a tissue paper. After that, the weight of seeds was taken in gram with a balance sensitive to ten (10) g. In case of weight loss calculation, weight was taken from every sample and percent value was estimated based on the previous weight. The weight loss recorded from 3rd day after setting in shelf-life observation. It was calculated by following formula:

$$\textbf{Percent weight loss} = \frac{\textbf{Total weight loss}}{\textbf{Previous recorded weight}} \times \mathbf{100}$$

Peel was separated from fruits and the weight of peel was taken in gram with a balance sensitive to 10 g. The weight of non-edible part was taken separately with a balance sensitive to ten grams. Weight of non-edible portion was calculated with combined weight of seeds and peel. The percentage of non-edible and edible (pulp) portions were measured using the following formula (Sharma, 2004).

$$\textbf{Non edible portion (\%)} = \frac{\textbf{Weight of the non edible parts}}{\textbf{weight of the whole fruit}} \times \mathbf{100}$$

$$\textbf{Edible portion } (\%) = \frac{\textbf{Weight of the edible parts}}{\textbf{weight of the whole fruit}} \times \mathbf{100}$$

Shelf life of seeded banana germplasm was calculated by counting the days from harvesting up to last edible stage.

Assessment of chemical properties of selected seeded banana

Titratable acidity (TA) was measured according to the method by Rangana (1977), which was calculated using the following formula:

$$\textbf{Titratable acidity (\%)} = \frac{\textbf{Titre(ml)} \times \textbf{NaoH(0.1N)} \times \textbf{Vol. made up} \times \textbf{Citric acid equivalent wt. (64g)}}{\textbf{Volume of sample for titrate(5ml)} \times \textbf{weight of sample taken (10g)} \times \mathbf{1000}} \mathbf{100}$$

The remaining of the filtrated juice from TA determination was used to determine the pH of the fruit pulp. The pH was measured by using a glass electrode pH meter (GLP 21, Crison, Barcelona, EEC).

Total phenolics content was estimated spectrophotometrically using Folin-Ciocalteu reagent (Kahkonen et al. 1999). Results were expressed as mg garlic acid equivalent g^1 FW.

$$\textbf{Total phenol content} = \frac{\textbf{OD} \times \textbf{Volume made up (with 80\% ethanol)} \times \mathbf{100}}{\textbf{Aliquot taken} \times \textbf{weight of sample} \times \mathbf{1000}}$$

The TSS (%) of banana pulp was determined by using a digital refractrometer (BOECO Germany).

Assessment of organoleptic/sensory evaluation of selected seeded banana

At the fully ripe stage, it was completed. Ten members of the panel were chosen, and they were told to assign a number between 0 and 5 to each feature in order to assess the differences between the samples. Excellent received five points, very good received four, good received three, fair received two, poor received one, and very poor received zero.

In situ and *Ex situ* conservation

The 'VIVO Y12A' model was used to coordinate passport data pertaining to local/Bengali, English, and scientific names of seeded banana germplasm and locations of identification with their Global Positioning System (GPS). Standard passport data form developed by Bangladesh Institute of Nuclear Agriculture (BINA) was followed for the passport data collection. Germplasm of seeded banana were *in-situ* conserved. The *ex-situ* conservation of seeded banana was done at Germplasm Center (GPC), PSTU. In *ex situ* investigations, all the collected germplasm were planted in GPC and tagged with names.

Statistical analysis

The computer package "JMP pro14" was used to perform the analysis of variance. Duncan's Multiple Range Test (DMRT) was used to determine the mean differences between the treatments at the 1% and 5% probability levels.

Multivariate and survey data analysis

Pearson's correlation analysis was performed to determine the relationships among important physico-morphological traits of selected seeded banana germplasm. Correlation coefficients were used to evaluate the strength and direction of associations among hand weight, seed number, number of hands per bunch, and peel weight.

$$\mathbf{r} = \frac{\sum(\mathbf{x_i} - \bar{\mathbf{x}})(\mathbf{y_i} - \bar{\mathbf{y}})}{\sqrt{\sum(\mathbf{x_i} - \bar{\mathbf{x}})^2 \sum(\mathbf{y_i} - \bar{\mathbf{y}})^2}}$$

where,

$\boldsymbol{x_i}$ and $\boldsymbol{y_i}$ = individual observations of two variables,

$\bar{\boldsymbol{x}}$ and $\bar{\boldsymbol{y}}$ = denote their respective means.

PCA was conducted using standardized data to assess the multivariate relationship and variability among the selected seeded banana germplasm based on physico-morphological traits. PCA was performed to identify the major contributing variables responsible for germplasm differentiation and to visualize the distribution pattern of germplasm under saline ecosystem conditions.

$$\mathbf{Z} = \frac{\mathbf{X} - \boldsymbol{\mu}}{\boldsymbol{\sigma}}$$

where,

X = observed value,

μ = mean of the variable, and

σ = standard deviation.

The principal component scores were computed from linear combinations of standardized variables according to:

$$\mathbf{PC_i} = \mathbf{a_1x_1} + \mathbf{a_2x_2} + \mathbf{a_3x_3} + \cdots + \mathbf{a_nx_n}$$

where,

$\mathbf{a_n}$ = loading coefficient of each variable,

$\mathbf{x_n}$= standardized variable value.

Hierarchical cluster analysis was carried out using Euclidean distance and Ward's linkage method to evaluate genetic and morphological similarity among the selected germplasm. Euclidean distance between samples was estimated using the following equation:

$$\mathbf{d_{ij}} = \sqrt{\sum_{\mathbf{k=1}}^{\mathbf{n}} \left(\mathbf{x_{ik}} - \mathbf{x_{jk}}\right)^2}$$

The dendrogram was generated to classify the germplasm into distinct clusters based on their trait similarity.

where,

$\mathbf{d_{ij}}$ = Euclidean distance between samples i and j,

$\mathbf{x_{ij}}$ and $\mathbf{x_{jk}}$ = observed values of the $\mathbf{k^{th}}$ variable.

Farmer survey data were analyzed using frequency distribution and percentage analysis to describe farmer preferences, cultivation practices, disease prevalence, and utilization patterns of seeded banana in the coastal saline ecosystem. Percentage values were calculated using the following formula:

$$\textbf{Percentage} = \frac{\textbf{Frequency}}{\textbf{Total number of respondents}} \times \textbf{100}$$

χ^2 analysis was performed to determine associations among farmer responses, management practices, disease incidence, and production objectives using the following formula:

$$\chi^2 = \sum \frac{(\mathbf{O} - \mathbf{E})^2}{\mathbf{E}}$$

where,

O = observed frequency and

E = expected frequency.

Graphical visualizations including bar charts, prevalence plots, PCA scatter plots, correlation heatmap, and dendrogram were generated using Python programming language (Python version 3.12.2) with the assistance of pandas, matplotlib, seaborn, scikit-learn, and scipy libraries.

Results and discussions

Physical properties of selected seeded banana germplasm

Individual fruit weight, pulp weight and hardness of seed

The highest individual fruit weight (204.06 g), pulp weight (135.8 g) and best soft seed texture were observed in germplasm MB16 while germplasm MB05 performed the least (Table 1). Rahman et al. (2019) reported that maximum and minimum individual fruit weight of seeded banana was 200 g and 123 g respectively which is supported our present study. The primary cause of morphological variations within the same fruit type is variety variation (Ayala-Silva et al. 2009).

Table 1. Individual fruit weight, pulp weight and hardness of seed of selected fruits of seeded Banana

Germplasm	Individual fruit wt. (g)	Pulp wt. (g)	Hardness of seed
MB03	164.5b	105.07c	1.5c
MB05	124.34c	77.82d	2.0b
MB13	153.8b	116.50b	2.5a
MB16	204.06a	135.80a	1.0d
Level of significance	**	**	*
CV (%)	7.76	5.39	15.75

*Means in a column followed by the same letter (s) do not differ significantly analyzed by DMRT. CV= Coefficient of variation; **= Significant at 1% level of probability; *= Significant at 5% level of probability*

Peel weight, number of seed, seed weight of selected fruits of seeded banana

Maximum peel weight (63.25 g) was observed in germplasm MB16 while it was minimum in germplasm MB13. Germplasm MB13 gave the highest number of seed and maximum weight of seed were 198.88 and 5.28 g respectively (Table 2).

Table 2. Peel weight, number of seed, seed weight of selected fruits of seeded banana

Germplasm	Peel wt. (g)	Number of seeds	Seed wt. (g)
MB03	55.13b	140.22a	4.30c
MB05	42.0c	146.0b	4.52bc
MB13	32.02d	196.88a	5.28a
MB16	63.25a	126.0b	5.01ab
Level of significance	**	**	*
CV (%)	13.0	9.59	8.75

*Means in a column followed by the same letter (s) do not differ significantly analyzed by DMRT. CV= Coefficient of variation; **= Significant at 1% level of probability; *= Significant at 5% level of probability*

Number of hands/bunch, number of fingers/hand, bunch weight (kg/plant), weight of individual hand

The highest number of hands/bunch (7.55) was found in germplasm MB05 and this result was statistically similar with germplasm MB03 and MB13. Germplasm MB16 scored the highest results in parameters of number of fingers/hand, Bunch weight (kg/plant) and weight of individual hand (kg) but the lowest values were recorded randomly among the germplasm (Table 3). Tigabu et al. (2015) who also found that the maximum number of hands per bunch of (7.145) was recorded for Dwarf cavandish and the minimum (4.132) was recorded for the local check which is agreed the present study. Besides, the variation in hands/bunch might be due to the variation in height and girth of plant while same observation was also found by Yoseph et al. (2014).

Table 3. Number of hands/bunch, number of fingers/hand, bunch weight (kg/plant) and weight of individual hand of selected fruits of seeded banana

Germplasm	Number of hands/bunch	Number of fingers/hand	Bunch weight (kg/plant)	Weight of individual hand (kg)
MB03	7.45a	12.50b	15.81b	1.80b
MB05	7.55a	14.24a	13.89c	1.65b
MB13	7.30a	12.82b	14.97b	1.75b
MB16	6.96b	14.60a	21.05a	2.70a
Level of significance	**	*	*	*
CV (%)	8.26	3.53	9.05	5.0

*Means in a column followed by the same letter (s) do not differ significantly analyzed by DMRT. CV= Coefficient of variation; **= Significant at 1% level of probability; *= Significant at 5% level of probability*

Weight loss (%) at different days after storage (DAS) of seeded banana

The result revealed that all fruits showed a progressive loss of weight during storage period (Figure 1). The highest weight loss (%) was showed in germplasm MB03 whereas it was lowest in germplasm MB13. Hossain et al. (2017) opined that the weight loss of bananas occurred due to the loss of water from the fruits, microbial decay and storage room environment like temperature and humidity which is supported our present study.

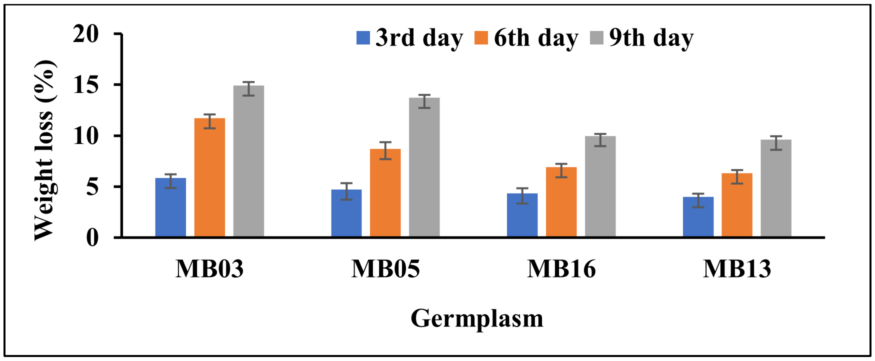

Fig. 1. Weight loss at different days after storage of seeded banana. Vertical bars represent the standard error

Pulp to peel ratio, shelf life, yield (t/ha) and pulp (%)

A variation for P: P ratio was found statistically non-significant in different selected seeded banana germplasm. Where MB13 showed the highest P: P ratio (3.63) while MB05 observed the lowest P: P ratio (1.85) and the longest shelf life (7.33 days) in this study. Similarly, Marta (2019) found that the varieties caused significant effects on pulp to peel ratio where it was the higher (6.46) in 'Gampa' and lowest (2.74) in 'AmritSagar'. The present findings are generally consistent with those of Rahman et al., who reported shelf life ranging from 5 to 9 days, fruit yield from 23.0 to 44.25 t/ha, and edible pulp content from 76.0% to 83.60% among different seeded banana germplasms. Similarly, in the present study, shelf life, yield, and edible pulp content varied considerably among germplasms, with MB16 recording the highest yield (49.46 t/ha) and MB05 the lowest (32.65 t/ha), while MB13 exhibited the highest edible pulp content (75.74%) and MB05 the lowest (62.58%).

Table 4. Pulp to peel ratio, shelf life, yield (t/ha) and pulp (%) of selected fruits of seeded banana

Germplasm	Pulp to peel ratio	Shelf life (days)	Yield (t/ha)	Pulp (%)
MB03	1.90	6.33b	37.16b	63.87bc
MB05	1.85	7.33a	32.65bc	62.58bc
MB13	3.63	5.33c	35.19b	75.74a
MB16	2.12	6.33b	49.46a	66.54b
Level of significance	NS	**	*	**

CV (%)	0.98	9.64	6.31	3.02

*Means in a column followed by the same letter (s) do not differ significantly analyzed by DMRT. CV= Coefficient of variation; NS= Non-significant; **= Significant at 1% level of probability; *= Significant at 5% level of probability*

Biochemical properties of selected fruits of seeded banana

The maximum titratable acidity (%) and phenol concentration (0.78% and 15.75 GAE mg/g, respectively) were found in germplasm MB03. Germplasm MB05 had the highest pH (6.43) and carotene content (0.95). Titratable acidity values are more closely associated with flavor than pH values and represent the total concentration of hydrogen ions (both dissociated and undissociated) (Yap et al., 2017). The quantity of hydronium ions in a food product determines its pH (Anyasi et al. 2015). According to a study, when the fruit ripens, an increase in organic acids causes the pH of seeded bananas to drop (Arvanitoyannis & Mavromatis, 2009). When it came to carotene content, MB05 (0.95) produced results that were statistically comparable to those of other genotypes. Fruit flesh color affects carotenoid content; bananas with yellow or orange flesh have the highest content (Englberger et al. 2006). The total phenolic content of seeded banana pulp (15.78 mg GAE/g extract), seed (19.46 mg GAE/g extract), and peel (11.23 mg GAE/g extract) was determined by Janavi et al. (2004). Phenolic compounds have protective effects in biological systems due to their potential to alter the activities of endogenous antioxidant enzymes as well as scavenge free radicals and chelate metal ions (Olszowy, 2019). Carotenoid production, which intensifies and even modifies the ripe fruit's color and features (Hornero-Mendez, 1994). TSS in seeded bananas varied significantly; MB16 had the greatest TSS (18%) and MB13 had the lowest TSS (13.83%) in this investigation (Table 5). In their study, Rahman et al. (2019) discovered that the pulp TSS percentages of various planted banana germplasm were 20.50% and 16.25%, respectively. the rise in TSS brought on by the transformation of complex carbohydrates into simple sugars. The fruit flesh's low citric acid concentration was revealed by the low acidity level. Due to the enhanced conversion of starch to sugar, ripe bananas typically have low reducing sugar content and high TSS, with reducing sugars acting as substrates for the banana's respiration process (Watharkar et al. 2021). Banana flavor is similarly influenced by the TSS parameter (Obenland et al. 2010).

Table 5. Bio-chemical properties of selected fruits of seeded banana

Germplasm	Titratable acidity (%)	pH	Phenol	TSS (%)	Total caroteniod
MB03	0.78a	3.90b	15.75a	17.67	0.85
MB05	0.20c	6.43a	14.39bc	16.82	0.95
MB13	0.38b	5.09c	14.79b	13.83	0.81
MB16	0.37b	4.36ab	13.54c	18.0	0.91
Level of sig.	**	**	*	**	NS
CV (%)	13.56	19.0	6.31	3.62	6.80

*Means in a column followed by the same letter (s) do not differ significantly analyzed by DMRT. CV= Coefficient of variation; NS= Non-significant; **= Significant at 1% level of probability; *= Significant at 5% level of probability*

Organoleptic/sensory evaluation

Organoleptic evaluation refers to the assessment of a substance or product based on its sensory characteristics, such as taste, smell, texture, appearance, and sound. It is commonly used to determine the quality, acceptability, or safety of a product through human senses. For example, in food science, an organoleptic evaluation might involve a taste panel assessing the flavor, color, texture, and aroma of a food product to determine its overall quality and consumer acceptability. Germplasm MB16 scored the highest result in organoleptic test in respect to all the parameter noted here e.g. (pulp color, sweetness, aroma, seed texture, and eye appeal) where other germplasm varied randomly. The lowest score was obtained in germplasm MB05 in all category (Table 6). Hardisson et al. (2001) and Belayneh et al. (2014) discussed how the color of the peel changes at different stages of ripening and how this affects customer acceptability.

Table 6. Organoleptic/sensory evaluation study of selected seeded banana germplasm

Germplasm	Pulp color	Sweetness	Aroma	Seed texture	Eye appeal
MB03	4.50b	4.70a	3.90ab	4.50b	4.50b
MB05	3.91d	2.50c	1.50c	2.28d	2.90d
MB13	4.20c	4.20b	3.80b	3.80c	3.50c
MB16	4.80a	4.82a	4.00a	4.80a	4.80a
Level of sig.	**	**	*	**	**
CV (%)	8.02	7.32	6.31	4.80a	4.00

*Means in a column followed by the same letter (s) do not differ significantly analyzed by DMRT. CV= Coefficient of variation; NS= Non-significant; **= Significant at 1% level of probability; *= Significant at 5% level of probability*

Bunch of banana | **Finger of banana** | **Berry (fruit)** | **Seed of fruit**

Seeded banana germplasm (MB03)

Seeded banana germplasm (MB05)

Seeded banana germplasm (MB13)

Seeded banana germplasm (MB16)

Figure. 2. Fruiting characteristics of different seeded banana germplasm

Multivariate and Correlation Analysis

Correlation analysis among physico-morphological traits

Pearson's correlation analysis (Sedgwick, Philip et al. 2012) was performed to evaluate the relationships among important physico-morphological traits of seeded banana germplasm under saline ecosystem conditions (Figure 3). The correlation matrix revealed substantial positive and negative associations among the studied traits.

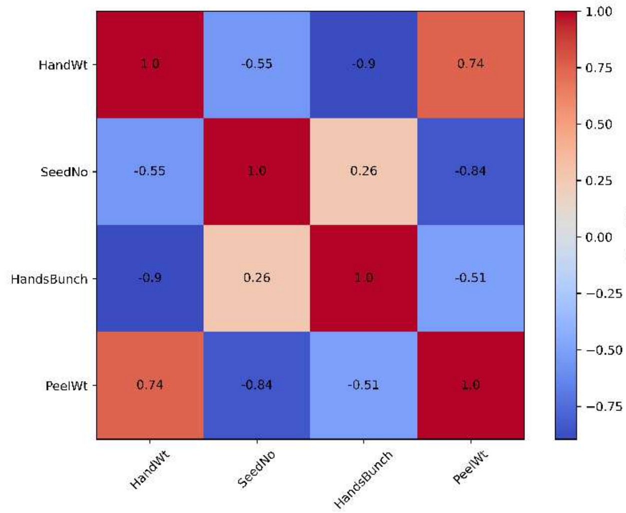

Figure 3. **Pearson's correlation matrix showing relationships among selected physico-morphological traits of seeded banana germplasm under saline ecosystem conditions. Color intensity indicates the strength of positive and negative correlations.**

A strong positive correlation was observed between individual hand weight and peel weight (r = 0.74), indicating that heavier banana hands tended to possess heavier peels. This relationship suggests coordinated biomass accumulation during fruit development, where larger fruits also accumulate greater peel tissue. The result was particularly evident in germplasm Sada (MB16), which exhibited both high hand weight and peel weight. Conversely, hand weight exhibited a modest negative connection with seed number (r = −0.55), indicating that a higher seed quantity may diminish edible fruit biomass. This may occur because developing seeds compete for assimilates and internal fruit resources during fruit growth. Germplasm Kali (MB13), characterized by higher seed number and comparatively lower hand weight, supports this observation. The strongest negative correlation was detected between hand weight and number of hands per bunch (r = −0.90). This finding indicates a clear trade-off between bunch size and individual hand development. Plants producing a greater number of hands per bunch may distribute available assimilates among more developing fruits (Ortiz et al.1998), thereby reducing individual hand weight. Seed number also exhibited a strong negative association with peel weight (r = −0.84), suggesting differential biomass partitioning between seed formation and peel development. Increased seed formation may redirect nutrients and assimilates away from peel tissue accumulation. A weak positive relationship was observed between seed number and number of hands per bunch (r = 0.26), indicating limited association between these two traits. Since the correlation strength was low, this relationship should be interpreted cautiously. Additionally, a moderate negative correlation was identified between number of hands per bunch and peel weight (r = −0.51), suggesting that bunch architecture may influence peel biomass accumulation.

PCA of selected germplasm traits

PCA was performed (Abdi et al. 2010) to evaluate the multivariate relationships among important physico-morphological traits of seeded banana germplasm cultivated under saline ecosystem conditions. The PCA scatter plot clearly separated the four germplasm into distinct groups based on trait variation, indicating substantial phenotypic diversity among the studied materials **(Figure 4)**.

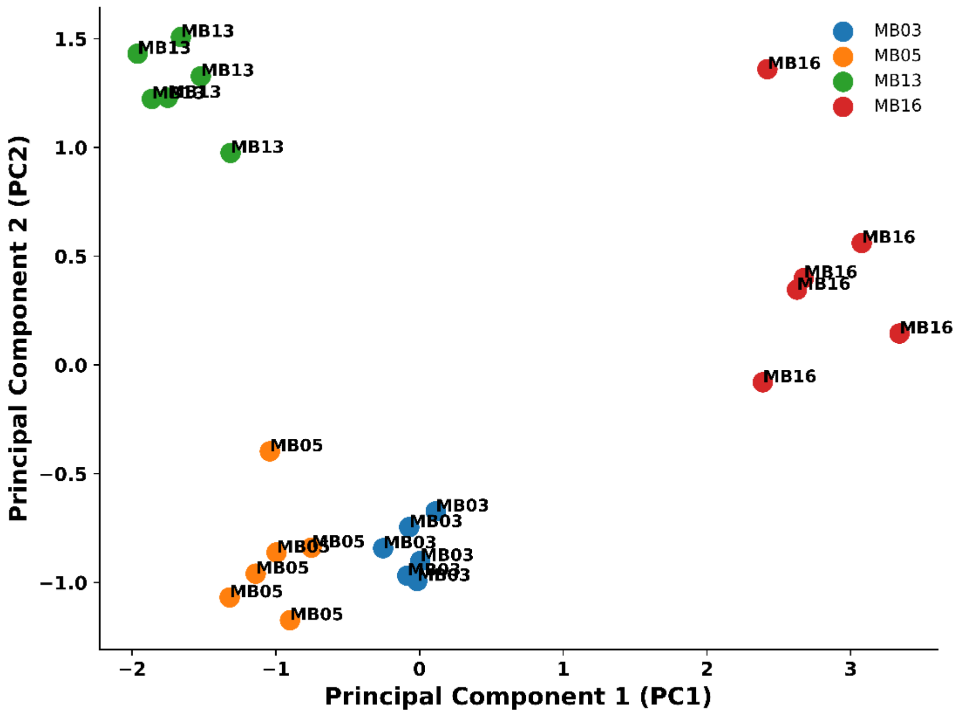

Figure 4. PCA scatter plot showing the distribution and clustering pattern of four seeded banana germplasm based on selected physico-morphological traits under saline ecosystem conditions.

The PCA results demonstrated clear discrimination among the four seeded banana germplasm (Osorio-Guarin, Jaime Andrés, et al. 2024). Germplasm MB16 was distinctly separated on the positive side of PC1, whereas MB13 and MB05 were distributed on the negative side of PC1. MB03 occupied an intermediate position near the center of the PCA plot. This separation indicates considerable variability among germplasm in relation to fruit morphology and biomass-related traits. The loading matrix revealed that PC1 was positively associated with individual hand weight and peel weight (Bantayehu et al. 2024), while seed number and number of hands per bunch contributed negatively to this component **(Table 7)**.

Table 7. Contribution and biological interpretation of major physico-morphological traits in PCA of seeded banana germplasm

Trait	PCA loading trend	Biological interpretation
Hand weight (+0.549)	Strong positive contribution to PC1	Indicates greater fruit biomass accumulation and larger fruit size
Peel weight (+0.532)	Strong positive contribution to PC1	Reflects increased structural tissue and peel biomass development
Seed number (−0.452)	Negative contribution to PC1	Suggests increased reproductive investment at the expense of edible biomass
Number of hands per bunch (−0.459)	Negative contribution to PC1	Indicates possible assimilate competition among developing hands

Therefore, germplasm positioned on the positive side of PC1 were characterized by heavier hands and higher peel biomass, whereas germplasm located on the negative side exhibited comparatively higher seed number and greater bunch architecture traits. Germplasm MB16 showed strong positive association with hand weight and peel weight, which agrees with its superior performance in yield and fruit quality traits observed in the present study (Danarto et al. 2015). The distinct positioning of MB16 on the positive axis of PC1 indicates that this germplasm possesses favorable fruit biomass accumulation characteristics and may represent a promising genotype for cultivation and breeding programs in saline ecosystems. On the other hand, MB13 was strongly associated with higher seed number and greater number of hands per bunch, as indicated by its negative PC1 and positive PC2 distribution. This suggests that assimilates in MB13 may be preferentially allocated toward seed development rather than edible fruit biomass accumulation. The comparatively high seed abundance of MB13 likely contributed to reduced individual hand weight and peel development. Germplasm MB05 clustered separately with negative PC1 and negative PC2 values, indicating relatively lower performance in most biomass-related traits. This result corresponds with its lower fruit weight, pulp weight, and yield performance observed during the experiment. The PCA loading pattern further demonstrated that hand weight and peel weight were closely associated traits, while seed number exhibited an inverse relationship with fruit biomass parameters. These findings support the correlation analysis and suggest that resource allocation among fruit tissues plays an important role in determining fruit quality characteristics in seeded banana germplasm (Ortiz et al.1998).

Cluster analysis of seeded banana germplasm

Hierarchical cluster analysis based on physico-morphological traits revealed substantial variability among the four seeded banana germplasm (Figure 5). The dendrogram grouped the germplasm into distinct clusters according to similarities in fruit biomass, seed characteristics, and bunch architecture traits. Germplasm MB16 formed a distinctly separated cluster with the highest Euclidean distance from the remaining germplasm, indicating pronounced phenotypic divergence in morphological and yield-related traits. This separation may be associated with its superior performance in individual hand weight, peel weight, bunch weight, pulp weight, and overall yield observed in the present study. In contrast, MB03 and MB13 showed relatively closer clustering patterns, suggesting moderate similarity in certain fruit and bunch characteristics.

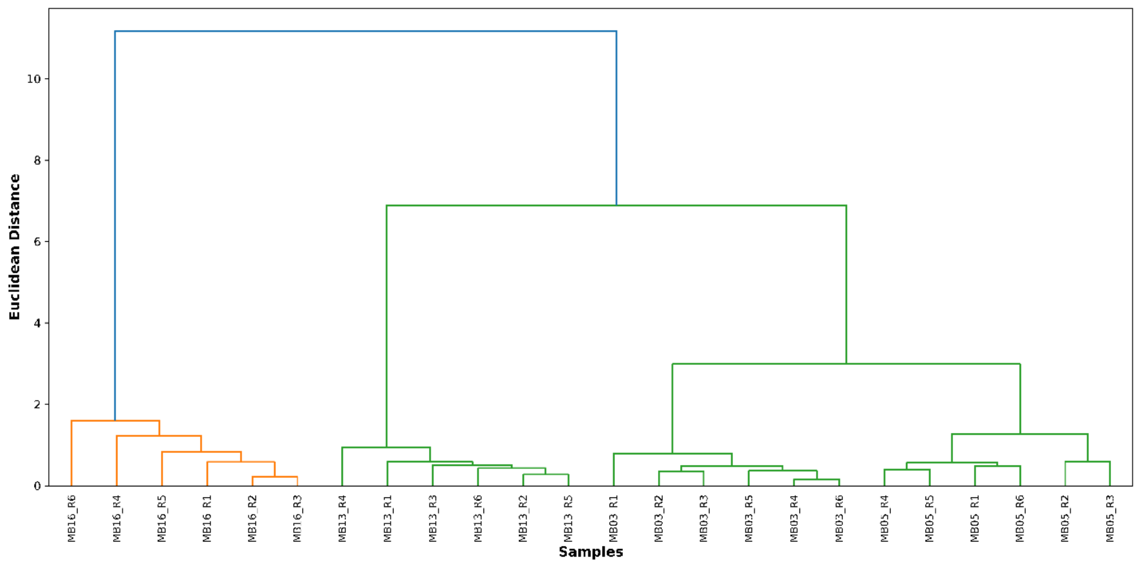

Figure 5. Hierarchical cluster dendrogram showing similarity relationships among seeded banana germplasm based on physico-morphological traits using Euclidean distance analysis

However, MB13 maintained partial separation due to its comparatively higher seed number and pulp percentage. Germplasm MB05 occupied an intermediate cluster position but remained distinct from MB16 because of its comparatively lower fruit biomass and yield performance. The clustering pattern strongly supported the PCA and correlation analyses, where MB16 was positively associated with fruit biomass accumulation traits, while MB13 showed stronger association with seed-related characteristics. The large Euclidean distance observed between MB16 and the other germplasm suggests considerable phenotypic diversity, which may be valuable for future breeding and germplasm improvement programs. Biologically, the clustering pattern indicates that assimilate partitioning may play an important role in fruit development among seeded banana germplasm. Germplasm with greater biomass accumulation capacity tended to produce heavier fruits and peels, whereas genotypes characterized by higher seed abundance showed comparatively reduced edible biomass accumulation. Similar clustering behavior based on fruit morphological and yield traits has been reported in banana germplasm characterization studies by Uddin et al. (2018), Anyasi et al. (2015), and Rahman et al. (2019).

Farmer survey and cultivation practice analysis of seeded banana in salt ecosystem

Frequency and percentage analysis of farmer responses

Frequency and percentage analyses revealed considerable variation in farmer perceptions and cultivation practices associated with seeded banana production in saline ecosystems (Table 7). The majority of respondents were directly involved in farming activities, indicating the agricultural importance of seeded banana cultivation in the coastal region. Artificial propagation was predominantly practiced by the farmers, whereas natural propagation was rarely observed. Among the major diseases reported, Panama disease showed the highest frequency followed by Sigatoka disease, suggesting that fungal diseases remain important constraints affecting seeded banana cultivation under saline conditions. Insect infestation by caterpillars was comparatively lower among the surveyed farmers.

Table 8. Frequency and percentage distribution of farmer responses regarding cultivation practices, disease incidence, utilization, and varietal preference of seeded banana in saline ecosystems

Category	Variable	Frequency	Percentage (%)
Occupation	Farmer	65	45.77
	Others	54	38.03
Propagation practice	Artificial propagation	120	84.51
	Natural propagation	0	0.00
Disease incidence	Sigatoka disease	29	20.42
	Panama disease	39	27.46
	Nematode infestation	19	13.38
	Bacterial disease	16	11.27
Insect infestation	Caterpillar attack	11	7.75
Production objective	Commercial production	102	71.83
Farmer preference	Interest in improved variety release	106	74.65
Utilization pattern	Vegetable purpose	100	70.42
	Fuel purpose (dried leaf)	107	75.35
	Fodder purpose	94	66.20

Most respondents cultivated seeded banana for commercial purposes, indicating its economic importance in coastal farming systems. A high proportion of farmers also expressed interest in the release of improved seeded banana varieties possessing desirable fruit quality and yield characteristics. Regarding utilization patterns, dried banana leaves were widely used as fuel material, while banana leaves and other plant parts were also commonly utilized as fodder and vegetable purposes. These findings demonstrate the multifunctional importance of seeded banana in coastal farming communities and highlight the necessity for improved germplasm development and sustainable cultivation strategies.

Disease prevalence analysis

Disease prevalence analysis revealed that Panama disease was the most frequently reported disease among the surveyed farmers, followed by Sigatoka disease (Figure 6). Nematode and bacterial diseases showed comparatively lower prevalence, while caterpillar infestation was least observed. These findings indicate that disease pressure remains an important production constraint in coastal seeded banana cultivation systems.

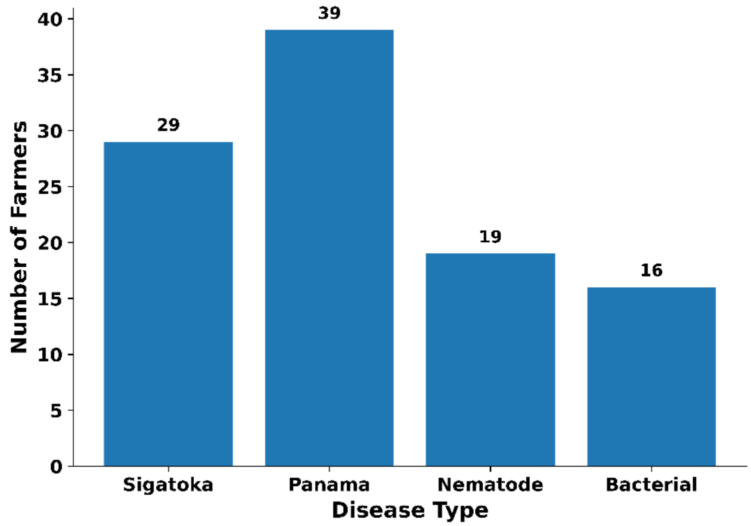

Figure 6. Prevalence of major diseases affecting seeded banana cultivation in saline ecosystem areas.

Propagation method analysis

The survey findings indicated that artificial propagation was predominantly adopted by the farmers for seeded banana cultivation, while natural propagation was rarely practiced (Figure 7). The preference for artificial propagation may be associated with better plant establishment and easier management under saline environmental conditions.

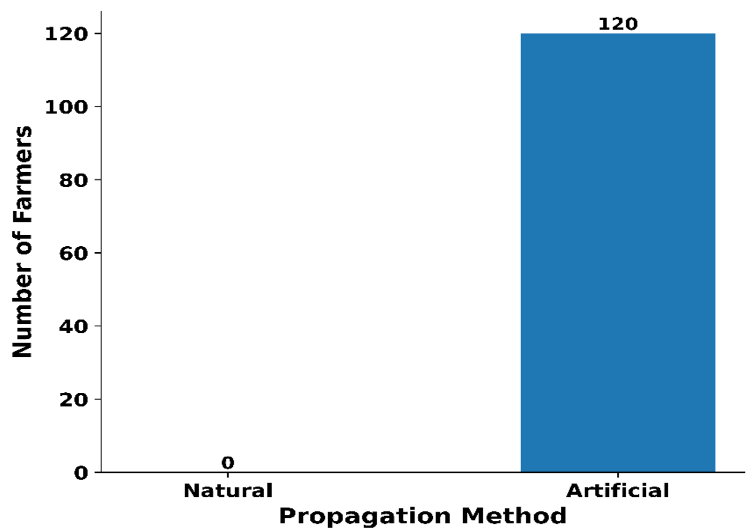

Figure 7. ***Propagation methods practiced by farmers for seeded banana cultivation in saline ecosystems.***

Improved variety interest analysis

A large proportion of farmers expressed interest in improved seeded banana varieties possessing superior fruit quality and productivity traits (Figure 8). The result indicates strong farmer demand for germplasm characterized by soft seed texture, improved taste, reduced seed abundance, and better yield performance.

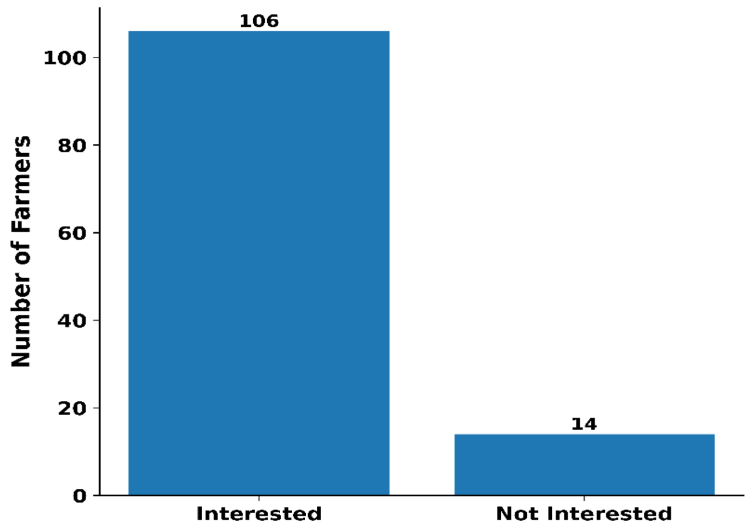

Figure 8. Farmer interest in improved seeded banana varieties in coastal saline areas.

Production purpose analysis

Most respondents cultivated seeded banana primarily for commercial purposes rather than personal consumption (Figure 9). This finding highlights the economic significance of seeded banana cultivation in coastal farming communities and suggests its potential contribution to rural livelihoods in saline ecosystem areas.

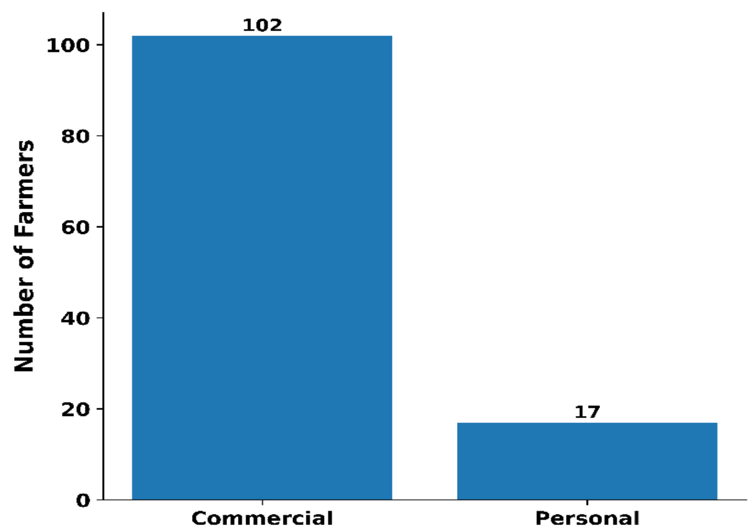

Figure 9. Production objectives of seeded banana cultivation among surveyed farmers.

Finally, the frequency distribution and farmer response analyses demonstrated that seeded banana serves important economic and multipurpose roles in coastal farming systems. Farmers showed strong interest in improved germplasm possessing desirable fruit quality and yield characteristics, indicating the necessity for further germplasm improvement and conservation efforts.

Association analysis of farmer responses using Chi-square test

Chi-square (χ^2) analysis (Satorra et al. 2001) was performed to determine the associations among farmer practices, disease prevalence, propagation methods, and production objectives of seeded banana cultivation in the salt ecosystem. The analysis evaluated whether farmer responses regarding disease incidence, irrigation practices, propagation methods, and management practices were significantly associated with commercial production and varietal preferences. The results of the Chi-square tests are presented in Table 11.

Table 11. Association among farmer practices, disease prevalence, and production objectives of seeded banana cultivation based on Chi-square analysis

Variable 1	Variable 2	χ^2 value	p-value	df	Significance
Panama disease	Commercial production	0.0365	0.8485	1	Not significant
Irrigation practice	Commercial production	0.0000	1.0000	1	Not significant
Interest in improved variety	Sigatoka disease	3.6683	0.0555	1	Not significant
Farmer occupation	Artificial propagation	0.0000	1.0000	0	Not significant
Natural propagation	Panama disease	0.0000	1.0000	0	Not significant
Fertilizer application	Commercial production	0.0000	1.0000	1	Not significant
Bagging practice	Caterpillar infestation	0.0000	1.0000	0	Not significant

Note: *χ^2 = Chi-square value; df = degrees of freedom. Associations were considered statistically significant at $p < 0.05$. "Not significant" indicates absence of statistically detectable association between the tested variables. Degrees of freedom equal to zero occurred due to lack of variation or identical response distribution within contingency table categories.*

The analysis revealed that most of the tested associations among farmer practices, disease incidence, and production objectives were statistically non-significant ($p > 0.05$). Panama disease occurrence showed no significant association with commercial banana production, indicating that disease incidence did not substantially influence production orientation among surveyed farmers. Similarly, irrigation practice, fertilizer application, and propagation method exhibited no significant relationship with commercial production practices. Farmer interest in the release of improved banana varieties showed a comparatively stronger association with Sigatoka disease occurrence ((χ^2) = 3.67, p = 0.055), although the relationship remained statistically non-significant at the 5% probability level. This result suggests that disease pressure may partially influence farmer demand for improved or disease-tolerant banana germplasm. Similar observations regarding farmer preference for disease-tolerant banana cultivars were also reported by Rahman et al. (2019) and FAO reports on traditional banana production systems. The absence of significant associations in several variables may indicate that seeded banana cultivation in coastal saline ecosystems is largely managed through traditional and experience-based farming practices rather than specialized management interventions. Additionally, the limited variation among farmer responses and relatively small sample categories may have contributed to the non-significant statistical outcomes. Similar findings were reported by FAO (2022), where traditional management practices and local adaptation strategies were identified as major determinants of cultivation behavior in smallholder farming systems. From a biological and agricultural perspective, the non-significant associations observed in the present study may suggest that farmers in saline coastal ecosystems rely on generalized cultivation strategies irrespective of disease prevalence or production purpose. Seeded banana cultivation in these regions is predominantly traditional and homestead-oriented, where management practices are often influenced by resource availability, local adaptation, and inherited farming knowledge rather than disease-specific interventions. Similar observations have been reported in traditional banana production systems where socio-economic and environmental factors strongly influence cultivation practices and varietal adoption (Gowen, 1995; Bose et al. 1999).

Conclusion

Four types of seeded banana germplasm were considered for characterization in this study. After analyzing the physico-chemical and organoleptic properties, it may be concluded that among these seeded banana germplasms, MB16 was the best one because of its outstanding performance in respect of soft seed texture, high TSS content, good taste, no odd flavor, moderate (2^{nd} highest) pulp %, yield and highly consumers preferences and our research support it. The germplasm also demonstrated favorable biomass accumulation characteristics as revealed by correlation analysis and PCA. Strong positive association between hand weight and peel weight, together with the negative association between seed number and fruit biomass traits, indicated the importance of assimilate partitioning in determining fruit quality characteristics of seeded banana. Multivariate analysis including PCA and hierarchical cluster analysis clearly differentiated the germplasm based on morphological and yield-related traits. Germplasm MB16 formed a distinct group associated with superior fruit biomass and quality traits, whereas MB13 was characterized by higher seed abundance and pulp percentage. These findings suggest substantial variability among the studied germplasm, which may be useful for future breeding, conservation, and varietal improvement programs in saline environments. Farmer survey analysis revealed strong farmer interest in improved seeded banana varieties suitable for coastal ecosystems. The majority of farmers cultivated seeded banana for commercial purposes and preferred varieties possessing good taste, soft seed texture, and better marketability. Disease prevalence, particularly Panama and Sigatoka diseases, was identified as an important production constraint in the study area. However, Chi-square analysis indicated that most farmer practices and production objectives were not significantly associated with disease prevalence, suggesting that cultivation largely depends on traditional management systems and local adaptation practices. Considering overall physico-chemical properties, sensory acceptability, yield performance, multivariate statistical analyses, and farmer preference, germplasm MB16 was identified as the most promising seeded banana germplasm for cultivation and conservation in coastal saline ecosystems of Bangladesh. The collected germplasm was successfully conserved under ex situ conditions at the GPC, PSTU. Further large-scale multi-locational and molecular studies are recommended to validate the stability, adaptability, and genetic potential of these germplasm for future crop improvement and sustainable banana production in salt-affected regions.

Data Availability

The corresponding author can provide the datasets used in this study upon reasonable request.

Declaration

Declaration of generative AI and AI assisted technologies in the writing process
Grammarly and Quillbot were used by the authors to check grammar and paraphrase sentences where needed throughout the development of this work. The authors examined and made any necessary edits to the content after using this tool.

Competing interests
The authors declare no competing interests.

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Author contributions
Mahbub Robbani, Jewel Howlader & Md. Nazmul Hasan Mehedi: Investigation, conceptualization, methodology, supervision and editing original draft; Md. Mesbah Uddin: Conduct experiment, data collection, chemical analysis and writing original draft; Md. Nesar Uddin & Md. AlAmin Talukder: Laboratory analysis, data accuracy, statistical analysis; Shahad shahriar: Statistical analysis, writing original draft; Tusar Kanti Roy: Data accuracy, statistical analysis; prepared and edited the manuscript. All authors carefully read and authorized the final manuscript.

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