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RESEARCH ARTICLE

Morphological Diversity Analysis using Existing and Endangered Banana Genotypes of Bangladesh

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Abstract

This study evaluated morphological diversity among 24 existing and endangered banana genotypes in Bangladesh from January 2023 to May 2025. Significant variation was observed in vegetative growth, flowering, harvesting time, and yield traits. Pseudo-stem height ranged from 2.24 m in Mehersagor to 4.53 m in Neyali, while base girth varied from 15.90 cm in Ramkela to 90.20 cm in Goma Atia. Yield attributes also differed markedly: Grand Naine produced the heaviest bunches (18.3 kg), Mehersagor the highest number of hands per bunch (12.8), and Champa the greatest number of fingers per hand (15.5). Individual finger weight was highest in Mehersagor (215.47 g) and lowest in Madna (74.90 g). In case of harvesting the longer period (366.30 days) found in Dudhsagor whereas the shortest period (308.40 days) was recorded in Ramkela. Principal component analysis revealed that vegetative growth, crop duration, and yield traits contributed most to overall diversity, accounting for 75.45% of the cumulative variance across four components. These findings highlight substantial morphological and horticultural variation among Bangladeshi banana genotypes, underscoring their potential for cultivar selection, genetic conservation, and sustainable production strategies.

Keywords: Banana, Morphological diversity, Principal component analysis, Yield traits.

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Introduction

Banana is a perennial herb belonging to the *Musa* genus. Wild bananas are fertile and full of seeds and belong to *Musa acuminata* (AA) or *Musa balbisiana* (BB). The Musaceae family genome is complex, and four genomes are present, corresponding to the genetic constitutions of the four wild *Musa* species, i.e., *M. acuminata* (A-genome, 2n = 2x = 22), *M. balbisiana* (B-genome, 2n = 2x = 22), *M. schizocarpa* (S-genome, 2n = 2x = 22) and *M. textillis* (T-genome, 2n = 2x = 20) (Agindotan et al. 2006, Indrayanti et al. 2024). The plant is chopped down and discarded, primarily as garbage, after the fruit is harvested. The *M. paradisica* cultivar of banana is widely grown as a commercial crop in Bangladesh. Due to the enormous need for food among the general public, banana farming is growing daily (Rahman et al. 2014). They play a crucial role in food security, mainly as cooking bananas and plantains, serving as the leading globally exported fruit, and due to their high nutritional value, bananas are also beneficial for traditional medicinal practices (Tripathi et al. 2007, Musa et al. 2024).

In Bangladesh, banana (*Musa* spp.) is the second most important fruit crop, which belongs to the family Musaceae in the order Zingiberales. It is cultivated in tropical and subtropical regions worldwide. Banana fruits have high calorific value that is closely comparable to potatoes but are more easily digestible (Malikongwa et al. 2022). Bangladesh is the host to a diversity of bananas that occupy different ecological places. The diversity also reflects preferences in fruit size, shape, color and aroma as well as nutritional, medicinal andcultural values (Hoque 2008). Commercial growers usually remove the male bud after the last hands have set (Rahman and Akter 2019). Furthermore, bananas are an affordable fruit and abundantly available in the local supermarket since they can be cultivated in a very broad range of climate and environmental conditions (Rahman et al. 2014).

The top banana-producing countries of the world are India (15% of total production), China, Ecuador, Brazil, and the Philippines (5-6% each). About 15 to 20% of the world's banana production is traded internationally, with an annual value of about US $6 billion (Nayar 2010).

Banana production in Bangladesh can be divided into three systems: backyard, mixed production, and small-scale commercial production (Alam et al. 2021). Bananas are grown year-round in Bangladesh practically in Bogura, Mymensingh, Norsingdi, Rangamati, Noakhali, Barisal, Jessor, Khulna, Kushtia, Faridpur, Dhaka, and Rangpur are the major banana-growing regions. Amrit Sagar, Mehersager, Sabri, Kobri, Champa, Chini Champa, Bangla, Atia, Kanthali, Singapuri, Nepali, Kabuli, Jahaji, Agnishwar, Japkathali, Seeded banana, Anaji or Kancha Kola, and Singapuri, among other notable banana types grown in various parts of Bangladesh (BBS 2023).

The sustainable banana production system is supposed to be one of the main pillars of the sustainable food system, with minimal environmental impact, to support the much-needed focus on addressing world hunger and malnutrition, especially under the changing climate (Debnath et al. 2019). Agriculture is very important to Bangladesh's economy as it contributes to 17% of its total GDP. Bananas are considered one of the finest fruits and the most important in terms of food value, food security, food availability and above all, it is a crop that has a positive impact due to its profitability margins aimed at increasing household income and alleviating poverty. The morphological characterization of banana plants is essential for developing superior varieties, as it highlights the distinct traits of different banana ty Morphological identification can serve as a tool for evaluating relationships among various accessions (Ismail et al. 2021).

Bananas exhibit a high level of morphological and genetic diversity. Morphological characterization of banana is a crucial phase in the management of germplasm collection, aiding in the identification and offering insights into traits that contribute to effective conservation strategies and optimal usage (Hapsari et al. 2022). Each region features a distinct type of banana with unique external and internal characteristics (Ekawati et al. 2025). The morphological characters of banana plants were identified using the Banana descriptors book from the International Plant Genetic Resources Institute (IPGRI)- INIBAP. Plant descriptors for identity were pseudo-stem appearance, leaf habit, pseudo-stem color, sap color, petiole canal leave, petiole margin color, the shape of leaf blade base, and other characteristics described by Indrayanti et al. (2024). Additionally, assigning local names in regional dialects to cultivars based on their morphological traits could lead to many synonyms while preventing redundancy (Borborah et al. 2020). In general, differences in environmental conditions between areas may affect the genotype expressed in phenotypic appearance (Johnson et al. 2023). The specific banana variety influences the timing of fruit production and harvest. It takes about ten to twelve months for a banana plant to produce a single bunch and the fruits typically ripen in four to six months (Meher et al. 2025). Therefore, the research was undertaken to know the comparative performance of 24 accessions of banana at the Institute of Biological Sciences, University of Rajshahi to study the morphological characteristics, select the best cultivar(s) and find out the potentiality of different cultivars suitable at existing conditions.

Materials and Methods

The experiment was conducted at the Research Field of the Institute of Biological Sciences, University of Rajshahi. Bangladesh during the period from January 2023 to May 2025. The treatments consisted of a single factor, i.e., 24 banana accessions. The suckers of banana were used as planting materials which were collected from different regions of Bangladesh are presented in Table 1. Plant characterization is carried out to determine the morphological characteristics of a plant which can then be used as a basis for determining diversity in these varieties.

Table 1: Twenty-four banana cultivars were from different areas of Bangladesh.

Sl. No.	Cultivars name	Genomic Group	Habitat area
1	Amrit Sagor	AAA	Bogura
2	Agniswar/ Surjamukhi/Lal Kela	AAA	Khagrachari
3	Binasuti	ABBB	Satkhira
4	Botur Atia	BBB	Bogura
5	Champa	AAB	Rajshahi
6	Chini Champa	AB	Natore
7	Dudhsagor/Dudthsor	AAA	Khulna
8	Genasundari/Gera Kala	ABB	Moulovibazar
9	Goma Atia	BBB	Rajshahi
10	Jahaji/Singapuri/Kanaibashi/Nepali/ Basri/Kaboli	AAA	Rajshahi
11	Kabri Kola/Gine Kola/Bangla Kola/Shail Kola	AAB	Chattagram
12	Mehersagor/Giant Governor	AAA	Chapainowabganj
13	Neyali	BBB	Mymensing
14	Rongin Sagor	AAA	Khagrachari
15	Sabri	AAB	Bogura
16	Sareng Atia	BBB	Bogura
17	Grand Naine (G-9)	AAA	Bogura
18	Madna	AB	Jessore
19	Anaji Kola	ABB	Bogura
20	Kancha Kola	ABB	Rajshahi
21	Dhalpoush	ABB	Kishorgang
22	Kathali	ABB	Rajshahi
23	Japkathali	AB	Mymenshigh
24	Ramkela/Pahari Kola	AA	Sylhet

The single factor experiment was laid out in Randomized Complete Block Design with three replications. One accession represents one treatment and one plant in an accession represent one replication. The land was high and the soil pH was 5.80-5.82 and thoroughly prepared by ploughing and cross ploughing followed by laddering. The fertilizer with the combination of N, P and K were applied as broadcast before final land preparation.

Data analysis

The morphological characters were observed for plant identification based on the criteria of plant and fruit morphological characters in the "Descriptors for Banana (*Musa* spp.)" (INIBAB 1996). Sample size was 10 for each character. Data were recorded following the parameters of Rahman et al. (2014). Duncan's multiple range test was used for the comparison of means at 95% confidence level ($p = 0.05$). Quantitative analysis was subsequently subjected to clustering analysis using SPSS version 25 windows (IBM SPSS Inc., Chicago, IL) software, using Euclidean distances and presented as a two dimensional dendrogram.

Result and Discussion

Variation of traits of 24 banana genotypes

The assessments took place during the flowering phase and prior to the bunch harvesting stage in both the mother plant and sucker production cycles. The phenotypic characteristics and vegetative yield were assessed and reported in accordance with Soares et al. (2012). 24 Banana genotypes showed significant variation for the pseudo-stem height (m), base girth (cm), days to flowering, no. of leaves/plant at flowering, days to bunch maturity, crop duration (days), hands/bunch, no. of fingers/hand, bunch wt (kg), bunch length (cm), bunch breadth (cm), finger length(cm), finger diameter (cm), individual finger wt (g), no of sucker (s). The result among the different characters has been presented in different tables and figures under the following sub-headings:

Vegetative characters, flowering and harvesting time of twenty-four banana cultivars of Bangladesh

There were significant variations among the 24 banana genotypes in all vegetative growth characters, flowering characters, and harvesting time (Table 2). Pseudo-stem height at 210 days after planting varied from 2.28 to 4.53 m where Amrit Sagar got the shortest and Neyali the tallest plant. Goma Atia produced the height base girth (90.20 cm) as compared to the lowest base girth in Ramkela (15.90 cm). The highest number of days required for flowering (269.80) is in Kabri kola, whereas the lowest number of days required for flowering (213.20) is in Ram Kela. The maximum number of leaves per plant in flowering time was found in Goma Atia (11.90), and the minimum number of leaves was in Jahaji (6.40). The highest days required for bunch maturity (102.70) are in Binisuti, whereas, the minimum days required for bunch maturity (86.80) are in Anaji Kola. The highest number of days to harvest (366.30) is in the Dudhsagor genotype, whereas the lowest (308.40) is in the Ramkela genotype.

Table 2: Yield attributes of 24 banana cultivars of Bangladesh.

Cultivars Name	Pseudo-stem Height (m) ($\bar{x}$±SEM)	Base Girth (cm) ($\bar{x}$±SEM)	Days to flowering ($\bar{x}$±SEM)	No. of leaves/Plant at flowering ($\bar{x}$±SEM)	Days to bunch maturity ($\bar{x}$±SEM)	Crop duration (Days) ($\bar{x}$±SEM)
Amrit Sagor	2.28±0.03^{lm}	42.50±1.02^{l}	221.10±2.77^{l}	10.50±0.47^{b}	100.80±1.66^{abc}	311.90±3.15^{i}
Agniswar	2.59±0.02^{j-m}	45.40±0.45^{jk}	255.90±1.43^{e}	8.60±0.26^{def}	99.70±0.59^{abc}	345.60±2.19^{cde}
Binasuti	3.14±0.00^{fh}	54.40±0.45^{f}	225.70±1.29^{k}	6.70±0.30^{hi}	102.70±0.51^{a}	328.40±1.46^{gh}
Botur Atia	3.94±0.01^{bc}	84.80±0.64^{c}	264.00±0.78^{c}	10.80±0.32^{b}	99.20±0.80^{abc}	363.20±0.84^{a}
Champa	2.97±0.03^{g-j}	63.70±0.51^{e}	241.40±0.68^{h}	10.40±0.40^{b}	96.00±0.47^{b-e}	337.30±0.44^{efg}
Chini Champa	2.83±0.00^{h-k}	45.70±0.47^{jk}	231.20±0.92^{j}	9.10±0.37^{de}	98.40±0.52^{a-d}	330.40±1.26^{fgh}
Dudhsagor	3.14±0.03^{fh}	51.50±0.40^{g}	274.80±0.86^{a}	6.80±0.24^{hi}	91.50±0.40^{e}	366.30±0.81^{a}
Genasundari	3.66±0.01^{bcd}	63.70±0.59^{e}	258.00±0.51d^{e}	8.10±0.27^{fg}	97.70±0.42^{a-e}	355.70±079^{abc}
Goma Atia	4.44±0.05^{a}	90.20±0.44^{b}	267.10±1.33^{b}	11.90±0.37^{a}	95.90±043^{b-e}	363.00±1.43^{a}
Jahaji	2.82±0.00^{h-k}	45.90±0.34^{ij}	246.60±0.34^{g}	6.40±0.30^{i}	94.30±0.30^{cde}	340.90±0.48^{def}
Kabri Kola	3.58±0.00^{b-e}	52.00±0.63^{g}	269.80±0.95^{b}	8.60±0.37^{def}	96.10±037^{b-e}	365.90±0.78^{a}
Mehersagor	2.24±0.00^{m}	35.00±0.44^{m}	227.90±0.43^{k}	10.60±0.30^{b}	96.30±0.30^{b-e}	324.20±0.53^{h}
Neyali	4.53±0.60^{a}	62.70±0.42^{e}	258.70±0.79^{de}	9.40±0.26^{cd}	96.30±0.51^{b-e}	355.00±1.19^{abc}
Rongin Sagor	2.55±0.00^{klm}	44.90±0.52^{jkl}	242.00±0.53^{h}	9.00±0.33^{def}	92.50±0.50^{de}	334.50±0.68^{e-h}
Sabri	3.26±0.02^{ef}	74.40±1.02^{d}	251.70±0.70^{f}	10.10±0.31^{bcd}	98.10±0.23^{a-d}	349.80±0.81^{bcd}
Sareng Atia	3.95±0.02^{b}	63.60±0.49^{e}	269.70±0.51^{b}	8.50±0.16^{ef}	96.30±0.42^{b-e}	366.00±0.47^{a}
Grand Naine	3.08±0.02^{gi}	50.50±0.58^{gh}	268.70±0.98^{b}	10.90±0.27^{b}	95.40±0.48^{b-f}	364.10±0.80^{a}
Madna	2.73±0.00^{ijk}	48.20±0.53^{hi}	235.30±0.36^{i}	8.20±0.24^{efg}	95.40±0.49^{b-e}	330.70±0.44^{fgh}
Anaji Kola	3.48±0.01^{de}	43.20±0.55^{kl}	252.40±0.88^{f}	7.50±0.16^{gh}	86.80±1.56^{f}	339.20±3.52^{d-g}
Kancha Kola	2.83±0.00^{h-k}	49.00±0.69^{h}	245.30±1.21^{g}	7.30±0.21^{ghi}	95.80±0.38^{b-e}	341.10±1.15^{def}
Dhalpoush	3.54±0.00^{cde}	43.80±0.46^{jkl}	239.20±1.15^{h}	9.00±0.25^{def}	92.30±0.47^{de}	331.50±1.35^{fgh}
Kathali	3.60±0.03^{b-e}	64.40±0.30^{e}	259.80±1.34^{d}	10.10±0.23^{bc}	96.10±0.43^{b-e}	355.90±1.28^{ab}
Japkathali	3.83±0.00^{bcd}	73.10±0.43^{a}	260.70±1.01^{d}	10.20±0.20^{bc}	98.70±0.21^{a-d}	359.40±1.04^{ab}
Ramkela	2.66±0.04^{jkl}	15.90±0.52^{n}	213.20±1.03^{m}	6.90±0.31^{hi}	95.20±0.80^{b-e}	308.40±1.39^{i}

Mean values followed by same lower-case letters (a, b etc.) are not significantly different ($p<0.005$) among different varieties of banana cultivates as determined by Duncan's Multiple Range Test (DMRT, by SPSS 25).

Yield contributing characters of twenty four banana cultivars of Bangladesh

Significant differences were observed among all yield contributing characters of 24 banana genotypes (Table 2 and 3). The highest number of hands per bunch was recorded in Meher Sagor (12.80) and the least in Ram Kela (6.10). The genotype Champa had the highest number of fingers per hand (15.50), whereas Ram Kela had the lowest (5.70). Finger length varied from 8.60 to 21.90 cm. Maximum Finger diameter was found in Amrit Sagor (4.60 cm) as against the minimum in Chini Champa (2.70 cm). Individual finger weight was found to be maximum

in Mehersagor (215.47 g) and minimum in Madna (74.90 g). Sabri banana produced the maximum number of suckers (5.90), whereas Ramkela produced the lowest number (2.50) of suckers in mature plant life.

Table 3: Yield contributing characters of twenty four banana cultivars of Bangladesh.

Cultivar name	Hands/Bunch ($\bar{x}\pm$SEM)	No. of Fingers/Hand ($\bar{x}\pm$SEM)	Bunch Wt (kg) ($\bar{x}\pm$SEM)	Bunch length (cm) ($\bar{x}\pm$SEM)	Bunch breadth(cm) ($\bar{x}\pm$SEM)
Amrit sagor	8.30±0.26^{g}	14.20±0.32^{cde}	13.80±0.49^{de}	46.50±0.37^{h}	31.10±0.37^{gh}
Agniswar	7.00±0.21^{ijk}	12.20±0.32^{i-l}	8.60±0.30^{ij}	50.30±0.42^{ef}	34.60±0.63^{cde}
Binasuti	7.00±0.25^{ijk}	11.70±0.30^{lm}	10.00±0.36^{h}	55.40±0.70^{d}	32.00±0.51^{fg}
Botur Atia	11.00±0.25^{bcd}	13.80±0.32e^{fg}	13.60±0.34^{ef}	51.40±0.76^{e}	35.90±0.90^{abc}
Champa	11.10±0.31^{cd}	15.50±0.34^{a}	13.60±0.42^{ef}	46.60±0.40^{h}	29.00±0.51^{ij}
Chini Champa	12.10±0.31^{ab}	15.00±0.33^{abc}	12.00±0.36^{g}	46.20±0.69^{h}	25.00±0.36^{k}
Dudhsagor	8.40±0.30^{g}	12.30±0.30^{h-l}	9.30±0.30^{hi}	59.10±0.60^{c}	34.50±0.34^{cde}
Genasundari	6.60±0.30^{jkl}	12.10±0.37^{j-m}	12.00±0.29^{g}	48.70±0.42^{fg}	36.80±0.49^{ab}
Goma Atia	9.80±0.20^{f}	14.00±0.25^{def}	13.80±0.24^{de}	47.80±0.57^{gh}	35.50±0.58^{a-d}
Jahaji	8.20±0.32^{gh}	13.10±0.37^{f-i}	14.80±0.32^{cd}	51.70±0.30^{e}	29.10±0.43^{ij}
Kabri Kola	10.10±0.37^{ef}	14.50±0.26^{b-e}	14.60±0.22^{cde}	49.70±0.42^{f}	28.60±0.40^{ij}
Mehersagor	12.80±0.41^{a}	14.80±0.32^{a-d}	17.30±0.30^{b}	62.10±0.48^{b}	36.30±0.39^{ab}
Neyali	8.50±0.16^{g}	12.70±0.21^{h-k}	10.10±0.45^{h}	37.40±0.47^{jk}	34.00±0.44^{de}
Rongin Sagor	10.80±0.32^{cde}	13.90±0.40^{def}	15.50±0.34^{c}	60.70±0.61^{bc}	36.40±0.49^{ab}
Sabri	9.80±0.20^{f}	12.90±0.27^{g-j}	12.30±0.30^{g}	43.60±0.54^{i}	29.00±0.42^{ij}
Botur Atia	7.80±0.24^{ghi}	14.20±0.24^{cde}	14.10±0.23^{de}	35.10±0.37^{l}	33.30±0.51^{ef}
Grand Naine	11.70±0.21^{bc}	15.30±0.30^{ab}	18.30±0.30^{a}	63.90±0.43^{a}	37.10±0.48^{a}
Madna	6.80±0.20^{jkl}	11.60±0.26^{lm}	9.20±0.38^{hi}	43.20±0.41^{i}	27.70±0.59^{j}
Anaji Kola	7.40±0.22^{hij}	11.60±0.30^{lm}	9.80±0.32^{h}	47.40±0.74^{gh}	35.20±0.68^{bcd}
Kancha Kola	6.20±0.32^{kl}	11.90±0.23^{klm}	9.40±0.34^{hi}	43.30±0.73^{i}	35.50±0.77^{a-d}
Dhalpoush	6.10±0.27^{l}	11.20±0.24^{m}	8.10±0.27^{j}	38.50±1.14^{j}	34.00±0.47^{de}
Kathali	10.10±0.23^{ef}	13.20±0.24^{fgh}	12.70±0.33^{fg}	32.50±0.45^{m}	30.20±0.44^{hi}
Japkathali	10.30±0.26^{c-f}	15.00±0.25^{abc}	14.00±0.25^{de}	36.10±0.52^{kl}	34.10±0.45^{de}
Ramkela	6.10±0.23^{l}	5.70±0.30^{n}	5.20±0.24^{k}	29.80±0.46^{n}	35.30±0.47^{bcd}

Mean values followed by same lower-case letters (a, b etc.) are not significantly different ($p<0.005$) among different varieties of banana cultivates as determined by Duncan's Multiple Range Test (DMRT, by SPSS 25).

Fig. 1 (a-l): A mature bunch of banana varieties available in Bangladesh. a = Amrit Sagor, b = G-9, c = Sabri, d = Jahaji, e = Bangla Kola, f = Chapa, g = Chini Champa, h = Meher Sagor, I = Dhalpoush, j = Kacha Kola, k = Kathali, and l = Botur Atia.

Table 4: Morphology of Finger and number of sucker produced by twenty- four banana cultivars of Bangladesh.

Cultivars name	Finger length (cm) ($\bar{x}$±SEM)	Finger diameter (cm) ($\bar{x}$±SEM)	Individual finger wt (g) ($\bar{x}$±SEM)	No of sucker (s) ($\bar{x}$±SEM)
Amrit Sagor	17.90±0.60^{d}	4.60±0.30^{a}	106.80±0.48^{i}	5.10±0.17^{a}
Agniswar	14.40±0.47^{fgh}	3.32±0.05^{fgh}	122.30±0.47^{g}	4.40±0.30^{ce}
Binasuti	13.50±0.34^{hij}	3.24±0.04^{ghi}	91.90±0.52^{j}	4.60±0.34^{c}
Botur Atia	15.80±0.24^{e}	4.20±0.04^{b}	159.20±0.61^{de}	3.30±0.30^{f-j}
Champa	14.34±0.14^{fgh}	2.93±0.05^{jk}	112.50±0.54^{hi}	3.50±0.26^{d-i}
Chini Champa	12.80±0.24^{ij}	2.70±0.05^{k}	91.00±1.59^{j}	3.80±0.24^{c-h}
Dudhsagor	14.50±0.26^{fgh}	4.06±0.12^{bc}	122.00±1.03^{g}	4.50±0.26^{cd}
Genasundari	15.28±0.13^{ef}	3.98±0.05^{bc}	135.00±1.62^{f}	2.80±0.24^{ij}
Goma Atia	12.60±0.22^{j}	3.42±0.04^{efg}	139.10±1.67^{f}	2.90±0.23^{hij}
Jahaji	19.01±0.18^{c}	3.39±0.05^{e-h}	201.00±0.51^{b}	4.60±0.30^{c}
Kabri Kola	13.13±0.19^{ij}	2.91±0.03^{jk}	121.37±0.39^{g}	3.20±0.24^{g-j}
Mehersagor	22.80±0.41^{a}	3.37±0.05^{e-h}	215.47±0.42^{a}	4.00±0.25^{c-g}
Neyali	13.00±0.33^{ij}	4.19±0.03^{b}	152.80±1.56^{e}	3.40±0.30^{e-j}
Rongin Sagor	15.80±0.26^{e}	3.11±0.02^{g-j}	120.44±0.12^{g}	4.20±0.24^{c-g}
Sabri	13.50±0.26^{hij}	3.16±0.03g^{hij}	116.63±0.22^{gh}	5.90±0.37^{b}
Botur Atia	13.20±0.41^{ij}	4.00±0.04^{bc}	141.60±0.83^{f}	4.10±0.23^{c-g}
Grand Naine	21.90±0.40^{b}	3.38±0.05^{e-h}	197.60±1.61^{b}	3.80±0.24^{c-h}
Tamil Nadu	11.10±0.23^{k}	3.08±0.01^{hij}	74.90±0.80^{k}	4.20±0.32^{c-g}
Anaji Kola	18.80±0.46^{c}	4.07±0.02^{bc}	166.20±1.51^{cd}	4.50±0.34^{cd}
Kancha Kola	14.50±0.34^{fgh}	3.63±0.05^{de}	152.90±0.43^{e}	4.20±0.32^{c-g}
Dhalpoush	21.28±0.21^{b}	3.57±0.04^{def}	172.30±0.47^{c}	4.30±0.30^{c-f}
Kathali	14.56±0.28^{fg}	3.83±0.02^{cd}	142.40±0.45^{f}	3.70±0.36^{c-i}
Japkathali	13.70±0.21^{ghi}	3.20±0.02^{g-j}	92.60±0.73^{j}	4.20±0.32^{c-g}
Ramkela	8.60±0.30^{l}	3.00±0.25^{ij}	111.50±0.70^{hi}	2.50±0.16^{j}

Mean values followed by same lower-case letters (a, b, etc.) are not significantly different ($p<0.005$) among different varieties of banana cultivates as determined by Duncan's Multiple Range Test (DMRT, by SPSS 25).

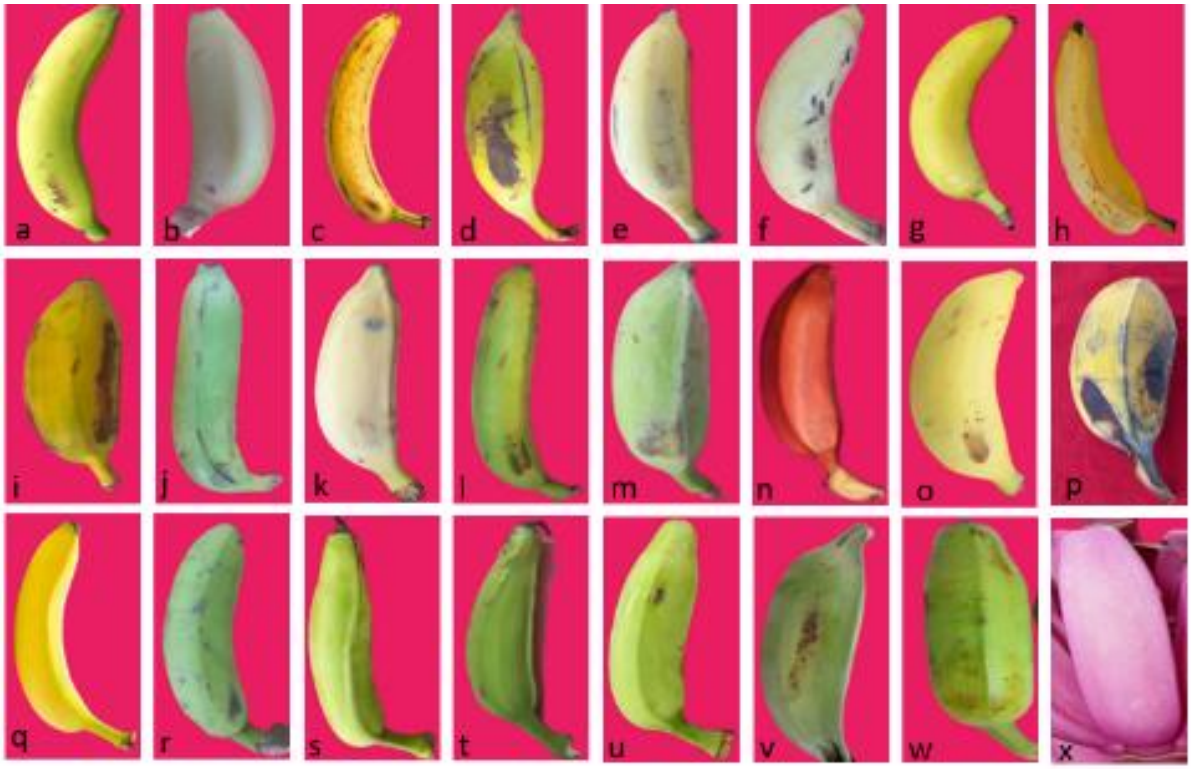

Fig. 2(a-x): Banana fruits of different varieties available in Bangladesh. a = Amrit Sagor, b = Agniswar, c = Binisuti, d = Botur Atia, e = Chapa, f = Chini Champa, g = Dudhsagor, h = Genasundari, i = Goma Atia, j = Jahaji, k = Kabri, l = Mehersagor, m = Nyali, n = Rongin Sagor, o = Sabri, p = Sareng Atia, q = G-9, r = Madna Kola, = Anaji Kola, t = Kancha Kola, u = Dhalpoush, v = Kathali, w = Japkathali, and x = Ramkela.

Principal component analysis (PCA)

Principal component analysis is a versatile statistical method for reducing a cases-by-variables data table to its essential features, called principal components (Greenacre et al. 2022). Principal component analysis is used to identify descriptors with greater ability to discriminate accessions (Novianti et al. 2025). The PCA based on the 15 morphological characters of 24 banana genotypes showed that the cumulative variance was 30.18% for PC1, 50.24 % for PC2, 67.08% for PC3, and 75.45% for PC4. The PC1 alone accounted for 30.18% of the total variation, mostly due to vegetative growth characters, flowering characters, crop duration, and yield-contributing characters. Individual finger weight and number of finger per hand had the highest contribution to PC1. PC2 accounted for 20.06% of the total variation, and most of the key characters contributing to it were vegetative growth characters, flowering characters, crop duration, and yield contributing characters. Crop duration, number of finger per hand, individual finger weight and number of sucker (s) had the highest contribution to PC2. The PC3 contributed for 16.84% of total variations,which was largely contributed to by vegetative growth characters, flowering characters, crop duration and yield contributing characters. Bunch breadth, finger diameter, Days to bunch maturity and crop duration had the highest contributions to PC3. These results are shown in Table 5.

Table 5: Principal component scores, eigen values and proportion of total and cumulative variance for 15 traits of 24 banana genotypes.

Traits	Principal component									
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
PH	-1.021	-2.297	-1.095	2.001	2.883	-0.150	0.010	1.399	-0.161	0.147
BG	-2.379	-0.228	-1.369	1.017	0.416	1.956	0.566	-0.722	1.066	0.076
DF	0.706	-0.595	-2.299	-0.928	-0.371	-0.734	-0.268	0.309	0.385	0.109
NLPF	-0.772	-0.972	-3.578	-0.662	-0.869	-0.719	0.435	0.539	0.358	-0.459
DBM	0.016	0.662	1.950	1.314	-1.936	1.181	-0.644	1.101	-0.123	-0.618
CD	0.223	1.538	1.463	-0.573	0.650	1.334	0.710	0.269	0.426	0.416
HB	-0.303	-1.934	0.980	0.920	-1.375	-0.685	1.680	-0.586	0.240	0.413
NFH	0.670	2.515	1.044	-0.174	0.947	-0.645	0.434	0.360	0.302	-0.393
BW	0.303	-2.241	-0.056	-0.771	-0.914	0.781	-1.396	0.465	0.000	0.803
BL	0.410	0.229	-1.954	2.002	-0.287	-0.531	-0.848	-1.190	-0.510	-0.444
BB	-0.880	-0.357	3.271	0.730	-0.904	-1.251	-0.924	0.495	0.569	0.135
FL	-1.708	0.209	1.272	0.467	0.071	0.458	0.180	-0.426	-0.387	0.370
FD	-1.525	-0.326	2.197	0.315	0.558	-1.654	-0.278	-1.118	0.600	-0.333
IFW	0.996	1.373	-0.374	-0.011	0.411	-1.460	0.428	0.363	-0.668	-0.219
NS	-6.435	1.018	0.564	-2.896	0.607	-0.051	-0.135	-0.072	-0.672	0.008
Eigenvalues	4.527	3.009	2.526	1.254	1.133	0.823	0.473	0.404	0.241	0.198
Variability (%)	30.18	20.06	16.85	8.36	7.55	5.45	3.15	2.70	1.61	1.32
Cumulative %	30.18	50.24	67.08	75.45	83.00	88.49	91.64	94.33	95.94	97.26

PC = Principal component; PH = Pseudo-stem height (m), BG = Base Girth (cm) DF =Days to flowering, NLPF = No. of leaves per plant at flowering, DBM =Days to bunch maturity, CD = Crop duration, HB = Hands/Bunch, NFH = Number of fingers per hand, BW = Bunch weight (kg), BL = Bunch length (cm), BB = Bunch breadth (cm), FL = Finger length (cm), FD = Finger diameter (cm), IFW = Individual finger weight(g) and NS = No. of sucker.

Correlation among morphological characters of 24 banana genotypes

The Pearson correlation among 15 traits of 24 banana genotypes is presented in Table 5. Plant height had a positive and significant correlation with base girth, days to flowering, number of leaves per plant at flowering, crop duration and finger diameter ($p<0.01$); bunch breadth ($p<0.05$); finger diameter ($p<0.05$). In contrast, plant height had a negative and significant correlation with bunch length, number of sucker(s) ($p<0.01$); and finger length ($p<0.05$). Base girth had a positive and significant correlation with days to flowering, number of leaves per plant at flowering, crop duration, hands per bunch, number of fingers per hand, bunch weight; days to bunch maturity. Base girth had only a negative and significant correlation with finger length. Days to flowering had positive andsignificant correlation with number of leaves per plant at flowering, crop duration, number of fingers per hand, bunch weight, bunch breadth, finger diameter, individual finger length and hands per bunch. Days to flowering had negative correlation with number of sucker(s). Number of leaves per plant at flowering had positive and significant correlation with hands per bunch, number of finger per hand, bunch weight and finger length and days to bunch maturity; crop duration. Days to bunch maturity had a positive and significant correlation with crop duration and had a negative and significant correlation with bunch breadth, individual finger weight, and bunch weight. Crop duration had a positive and significant correlation with hands per bunch, number of fingers per hand, bunch weight, finger diameter, bunch breadth, and individual finger length. On the other hand, crop duration had a negative and significant correlation with number of sucker(s). Hands per bunch had a positive correlation and were significantly

correlated with the number of fingers per hand, bunch weight, bunch length, finger length and individual finger weight. Hands per bunch had a negative correlation with finger diameter. The number of fingers per hand had a positive correlation and was significantly associated with bunch weight, bunch length, finger length and number of sucker. Hands per bunch had a negative relation with finger diameter. Number of fingers per hand had a negative correlation with bunch breadth, bunch weight had positive correlation and significant with bunch length, finger length and individual finger weight. Bunch length had positive and significant correlation with bunch breadth, finger length and individual finger weight. Bunch breadth had positive and significant correlation with finger length, finger diameter and individual finger weight. In contrast, bunch breadth had a negative and significant correlation with number of sucker(s). Finger length confirmed a positive and significant correlation with finger diameter, individual finger weight and number of sucker(s). Finger diameter had a positive and significant correlation with individual finger weight and number of sucker(s). Based on different parameters considered of the 24 banana genotypes showed a strong positive and significant correlation. The findings indicated that raising these characteristics can help boost agricultural production.

Table 6: Phenotypic correlations among fifteen traits of twenty four banana varieties at IBSc research field, University of Rajshahi.

	PH	BG	DF	NLPF	DBM	CD	HB	NFH	BW	BL	BB	FL	FD	IFW	NS
PH	1.00														
BG	0.59**	1.00													
DF	0.54**	0.60**	1.00												
NLPF	0.17**	0.45**	0.16**	1.00											
DBM	0.03	0.13*	0.11	0.135*	1.00										
CD	0.50**	0.57**	0.85**	0.164*	0.168**	1.00									
HB	0.03	0.27**	0.15*	0.556**	0.10	0.18**	1.00								
NFH	0.10	0.47**	0.35**	0.457**	0.06	0.31**	0.63**	1.00							
BW	0.01	0.31**	0.28**	0.459**	0.05	0.27**	0.69**	0.73**	1.00						
BL	-0.30**	0.09	0.09	0.05	0.01	0.07	0.38**	0.35**	0.46**	1.00					
BB	0.13*	0.01	0.204**	0.05	-0.148*	0.13*	0.10	-0.16*	0.02	0.22**	1.00				
FL	-0.16*	-0.14*	0.02	0.174**	0.11	0.04	0.22**	0.31**	0.44**	0.49**	0.29**	1.00			
FD	0.22**	0.12	0.227**	0.01	0.02	0.17**	-0.20**	0.01	0.00	0.06	0.30**	0.23**	1.00		
IFW	0.06	0.12	0.208**	0.10	-0.17**	0.14*	0.16*	0.11	0.35**	0.30**	0.40**	0.71**	0.24**	1.00	
NS	-.309**	0.08	-.235**	0.09	0.05	-0.27**	0.06	0.14*	0.09	0.08	-0.162*	0.22**	0.27**	0.11	1.00

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed). PH = Pseudo-stem Height (m), BG = Base Girth (cm) DF = Days to flowering NLPF = No. of Leaves per plant at flowering, DBM = Days to bunch maturity CD = Crop duration, HB = Hands per bunch, NFH = Number of fingers per hand, BW = Bunch weight(kg), BL = Bunch length (cm), BB = Bunch breadth (cm), FL = Finger length (cm), FD = Finger diameter (cm), IFW = Individual finger weight (g), NS = Number of sucker.

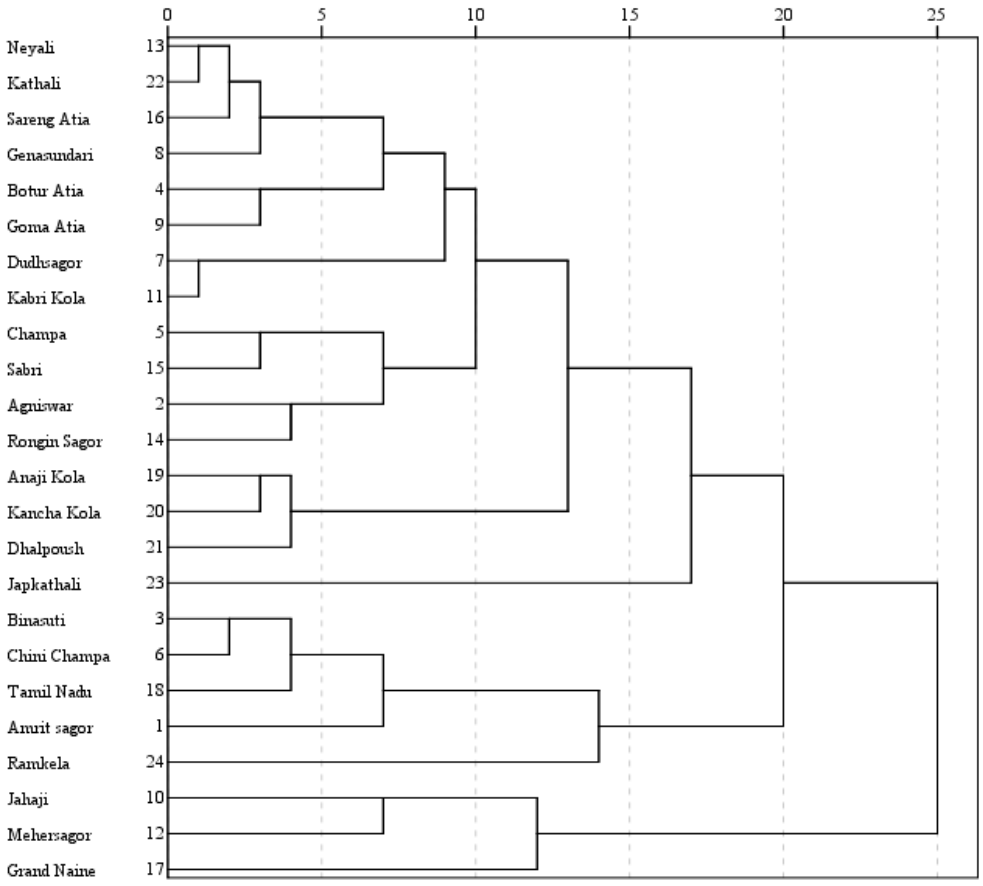

Fig. 3: Dendrogram showing clustering patterns of 24 banana (*Musa* spp.) genotypes of Bangladesh based on the morphological traits [Amrit sagor (AAA), Agniswar(AAA), Binasuti (ABBB), Botur Atia (BBB), Champa (AAB), Chini Champa (AB), Dudhsagor (AAA), Genasundari (ABB), Goma Atia (BBB), Jahaji (AAA), Kabri Kola (AAB), Mehersagor (AAA), Neyali (BBB), Rongin Sagor (AAA), Sabri (AAB), Sareng Atia (BBB), Grand Naine (AAA), Madna (AB), Anaji Kola (ABB), Kancha Kola (ABB), Dhalpoush (ABB), Kathali (ABB), Japkathali (AB) and Ramkela (AA)].

Conclusion

Existing and endangered banana genotypes showed a wide range of noteworthy variation in vegetative growth characteristics, flowering characteristics, crop duration, and yield-contributing characteristics. Amrit Sagar is the shortest plant, while Neyali is the tallest. Goma Atia exhibited the largest base girth (90.20 cm) compared to the smallest base girth recorded in Ramkela (15.90 cm). The longest duration needed for flowering was observed in Kabri kola (269.80 days), whereas the shortest duration for flowering was noted in Ramkela (213.20 days). The greatest number of leaves per plant during flowering was recorded in Goma Atia (11.90), and the least number of leaves was found in Jahaji (6.40). The maximum time required for bunch maturity was 102.70 days in Binisuti, while the minimum was 86.80 days in Anaji Kola. The longest harvest duration was 366.30 days for the Dudhsagor genotype, whereas the shortest was 308.40 days for the Ramkela genotype. To identify features with superior genotype selection potential, principal component analysis of banana genotypes was performed. In order to categorize the genotypes, cluster analysis of the table of genotypes was also completed, and the results validated the principal component analysis's clustering pattern. A Pearson correlation analysis was also conducted between the genotypes of table banana features under study.

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Author's contribution: SMSI designed the experiment, supervised the study, and corrected the manuscript. MAS collected conducted experiments, data collection and analysis and wrote the original draft of the manuscript. Both authors have read and approved the final manuscript.

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