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Genetic diversity assessment of indigenous mango (*Mangifera indica* L.) germplasm

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The study focused on genetic diversity valuation of mango (*Mangifera indica* L.) genetic resources available in subtropical conditions of Malihabad region of Lucknow, Uttar Pradesh, India. Among the 21 indigenous germplasm of Malihabad region assessed; Amin and Munjjar Aamin exhibited superior fruit yield (168.13±13.52 kg/tree and 250.21±15.04 kg/tree, respectively), signifying their adaptableness to the subtropical regions. The TSS (21.15±0.45°B) was higher in Taimuriya, acidity (0.43±0.05%) was in Gol Bhadaiyaa, ascorbic acid (33.9±1.2 mg/100 g) content in Aamin Abdul Ahad Khan, total sugars (18.1±0.14%) in Matka Gola, reducing sugar (6.5±0.52%) in August, total phenol (130.95±24.7 mg/100 g GAE) in Aamin Tehsil, and non-reducing sugar (12.7±0.42%) in Heere Hayat revealing the potential or superiority of indigenous mango germplasm for different biochemical parameters. Correlation studies on fruit physical, biochemical and yield attributes have provided in-depth knowledge and their interrelations. Fruit weight (g) showed a positive Pearson's correlation coefficient with fruit length (cm), fruit width (cm), fruit yield (kg/tree), pulp percentage (%), TSS (°B), acidity (%) and total sugar contents (%). Fruit yield was also correlated positively with biochemical parameters like total phenol (mg/100 g), acidity (%), ascorbic acid (mg/100 g), and TSS acid ratio. Principal Component Analysis revealed two principal components (PCs); PC-1 elucidated 35.1% variability, while PC-2 explicated 13.4%. This research identified Munjjar Aamin and Aamin as promising type that can be commercially multiplied for large scale cultivation in subtropical regions and further utilized in mango breeding in subtropics for the development of good quality, high yielding and climate-resilient mangos.

Keywords: Genetic, Germplasm, Indigenous, Mango, Morpho-biochemical, Subtropical, Traits

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Mango (*Mangifera indica* L.) is extremely treasured fruit of tropics and subtropics[1]. Mango has been cultivated for >4,000 years[2] initially propagated through seeds later on elite genotypes were propagated through vegetative means leading to ~1,000 mango cultivars[3]. Mango is deeply associated with the social culture of major mango producing countries like India, Indonesia, Thailand, China and Pakistan[4]. Mango is originated in the vicinity of Northeastern India, Bangladesh, Nepal, may also be in Northern Myanmar and Thailand[5,3,6], however, *Mangifera* genus diversity centre is in Malesia[5]. South East Asian tropical mangos are mainly polyembryonic in nature. In subtropical regions, monoembryonic type mangos are reported[7]. Mango has been distributed globally in tropical and subtropical regions along with the movement of people for trade[8,9,5]. Most of the mango produced in the country is consumed domestically[10]. Mangos are playing vital role in developing countries being the part of diet and rich in vitamins and minerals[11].

Mango is rich source of health promoting compounds like carotenoids and phenolics[12,13] which need to be associated with the traits related to the production efficiency. Considering the health-related benefits, the fruits and vegetables improvement programs are focused on bioactive compounds improvement[14]. Mango fruit quality improvement can be made by selecting superior genotypes or by developing novel hybrids. Previous reports suggest that wide variability exists for fruit physical, chemical and nutritional parameters[15-17]. Genetic diversity

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valuation is an obligatory prerequisite for their utilization in improvement of crop and conservation[18]. Fruit and plant morphological characters are also used for the identification of mango cultivars[19].

Malihabad Region in Lucknow, Uttar Pradesh is considered as a centre of diversity for mango having a rich diversity of named local cultivars, traditional varieties and unnamed local landraces because few large land owners were having ample space and have planted lots of seedling mango and trees were allowed to grow, flower and fruit. Due to which enormous mango genetic diversity was created. Farmers of the region had identified and selected unique indigenous mango germplasm and maintained over a long period of time. Although most of the indigenous mango germplasm have been disappeared from the region, however, many of them survived in the orchards and need to be conserved as these indigenous mango germplasms having specific traits are important for the future mango breeding programs.

ICAR-CISH had initiated on-farm conservation of indigenous mango germplasm of Malihabad region with the establishment of "Aam Vividhta Sanrakhchan Samiti" (Mango Diversity Conservation Society) by involving the custodian farmers. Several indigenous mango germplasms were identified for conservation[20] and local farmers are playing important role in their conservation. The indigenous mango germplasm of Malihabad region of Lucknow unveiled unique characteristics like differences in maturity time, color, and fruit size. Maturity time is important parameter for the conservation of indigenous mango germplasm because farmers prefer both early and late-maturing mango varieties[21]. The 21 indigenous mango germplasms which has been studied in the present study were registered for their unique traits with the 'Protection of Plant Varieties and Farmers' Rights Authority, New Delhi.

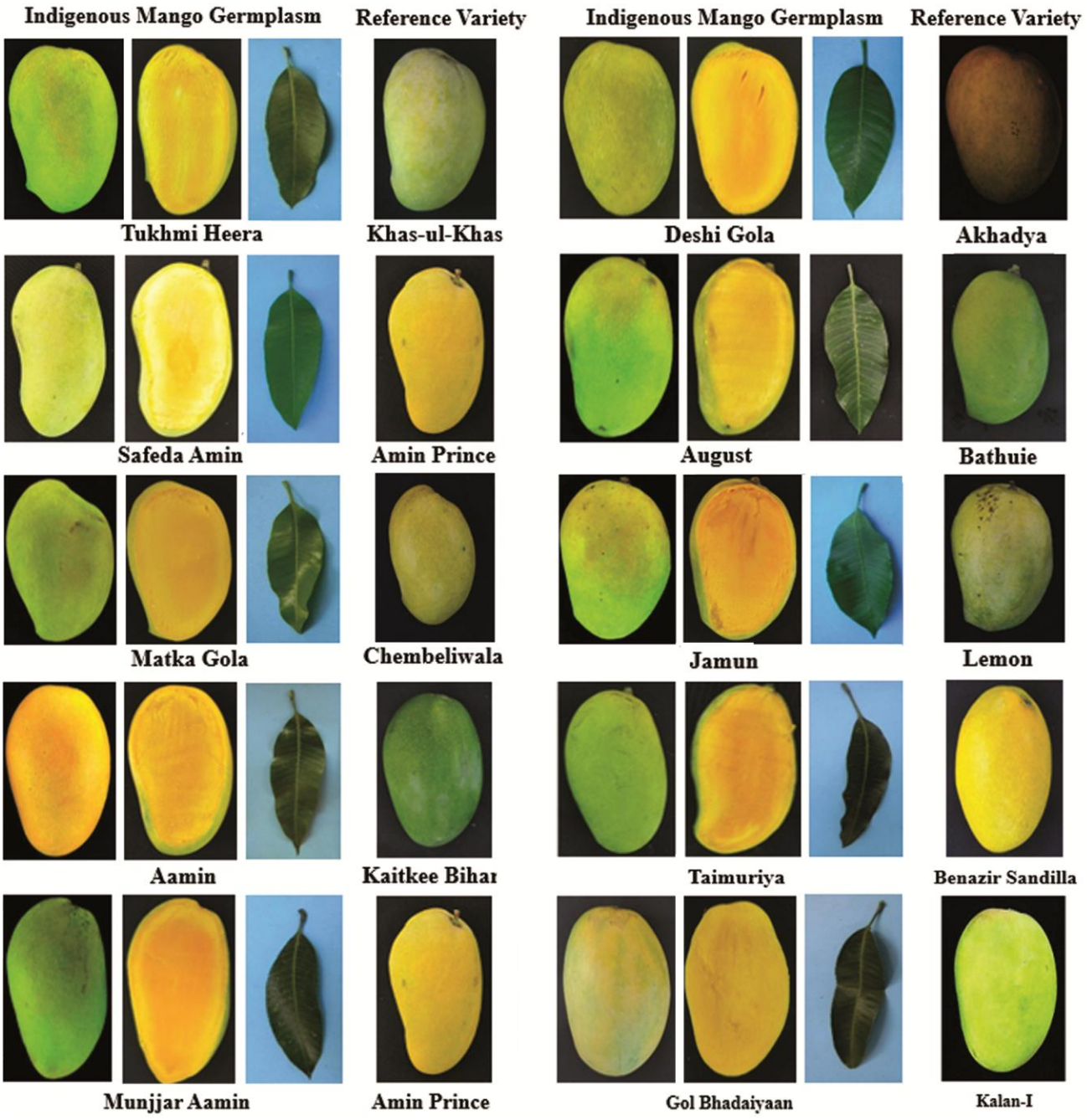
The development of elite mango hybrids through hybridization by selecting parents having specific traits is very long and tough process which also requires lots of resources. However, identification and selection of elite mango landraces is better alternative than tedious hybridization process. Therefore, there is an urgent need for harnessing the potential of indigenous mango germplasm of Malihabad region in order to identify climate resilient superior traditional mango genotypes. In this context, the present study was focused on the diversity valuation of indigenous mangos growing in subtropical conditions of Malihabad region for various traits and identification of superior mango indigenous germplasm/genotypes.

Materials and Methods

The name of 21 indigenous mango germplasm (Fig. 1) assessed and their details are presented in Table 1. A set of all 21 indigenous mango germplasm collected from Malihabad region were established at ICAR-CISH, Lucknow research farm at 10 m × 10 m spacing in randomized block design (RBD) with three replications (one plant/replication). All the indigenous mango plants were upheld with similar cultural practices. The experimental site is located at 26°45′ N latitude and 80°30′ E longitude having 123 m elevation above mean sea level. Each indigenous mango germplasm was denoted by three plants and total 63 number plants dispersed at ICAR-CISH research farm (Supplementary Fig. S1). The soils are typically loamy type which is well suited for mango cultivation. The area falls under subtropical climatic conditions. During summers, maximum temperature ranging from 35-45°C and minimum from 25-30°C. During winters, 20-25°C is maximum and 5-7°C is minimum temperature. The average annual rainfall is about 1000 mm. The observations were recorded for two successive years (2022-2023 and 2023-2024) and mean data of two years was statistically analyzed.

Fruit physical, biochemical and yield attributes

The total number of fruits were harvested and weighed for the yield observations. The fruit harvested randomly at physical maturity stage for various observations. Harvested fruit were washed under running tap water and then fruit surface was dried under running fan. After that fruits were stored in brown paper bags and kept for even ripening at room temperature. The fruit physical and biochemical observations were noted after the ripening of mango fruits. The physical parameters (Fig. 2) such as fruit weight (g), fruit length (cm), fruit width (cm), fruit thickness (cm), stone weight (g), stone length (cm), stone width (cm), pulp weight (g), peel weight (g) and pulp per cent (%) were measured using five (5) fruits samples from different replications and fruit weight in grams was recorded using digital top pan balance of randomly selected fruit samples. The physical dimensions were measured using digital vernier callipers in millimetres and centimetres. The fruit pulp was extracted and used for biochemical analysis. A digital hand refractometer (Atago, Japan) was used to assess the total soluble solids of fruits at room temperature. The findings were represented in degrees


Indigenous Mango Germplasm
Reference Variety
Indigenous Mango Germplasm
Reference Variety
Tukhmi Heera
Khas-ul-Khas
Deshi Gola
Akhadya
Safeda Amin
Amin Prince
August
Bathuie
Matka Gola
Chembeliwala
Jamun
Lemon
Aamin
Kaitkee Bihar
Taimuriya
Benazir Sandilla
Munjjar Aamin
Amin Prince
Gol Bhadaiyaan
Kalan-I

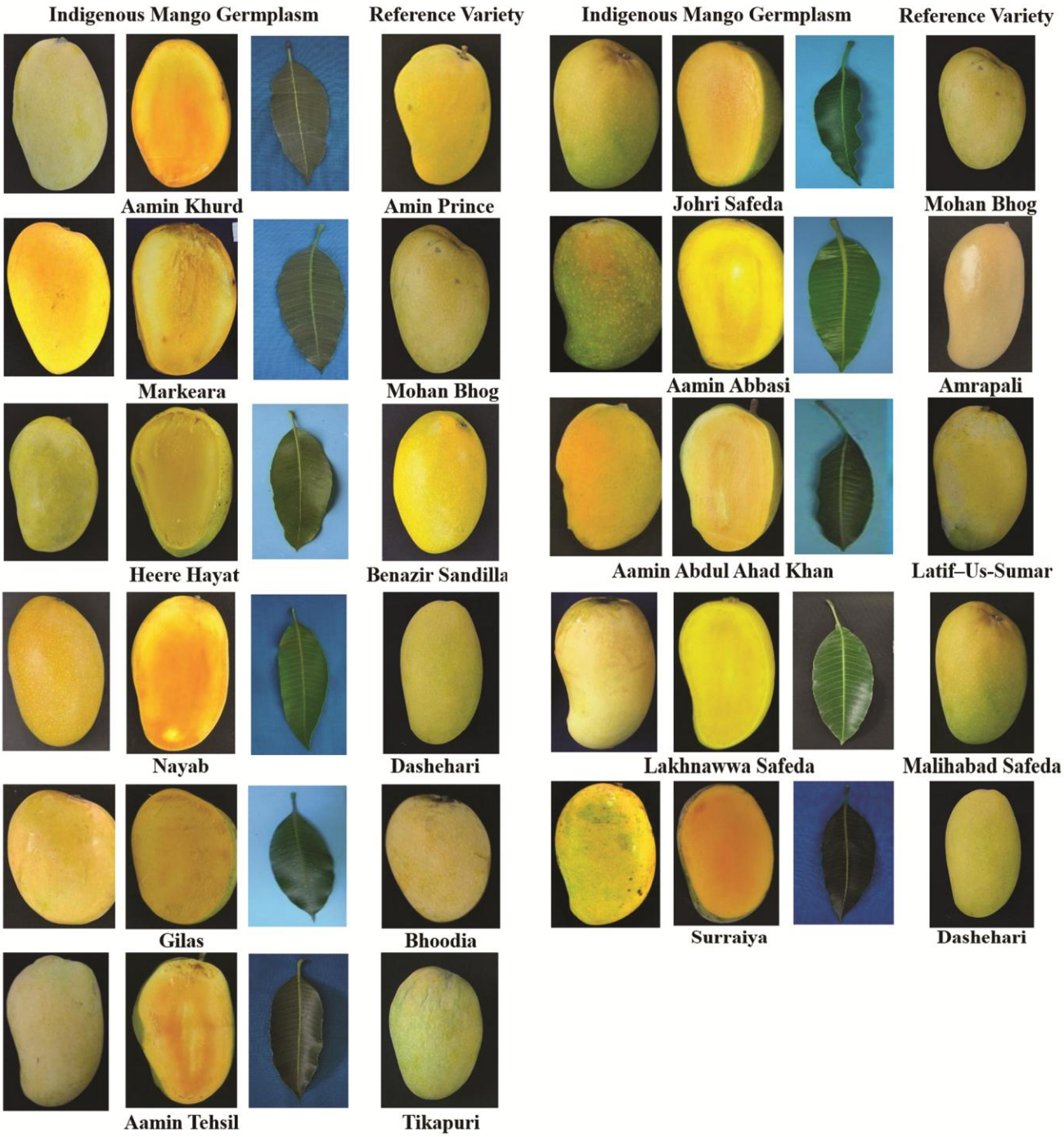


Fig. 1 — Fruit morphological traits of indigenous mango germplasm

Brix (°B). The total phenolic content was estimated from the ripe pulp of mango hybrids using Folin-Ciocalteu reagents at 750 nm through UV-VIS spectrophotometers[22]. Total carotenoids were estimated with modified procedure of Ranganna[23] using extraction solvents petroleum ether and acetone and read optical density at 452 nm using UV-VIS spectrophotometer.

Distinctness uniformity stability (DUS) descriptors[24] of mango was used to record the uniformity and consistency of indigenous mango germplasm (Supplementary Table S1).

Table 1 — List of indigenous mango germplasm and their corresponding source

S. No.	Mango Genotype, PPV&FRA Registration No. and Date	Farmers Name/ Community	Village/Tehsil	District	State	Latitude and Longitude
1	Tukhmi Heera (REG/2014/776 dated 26.09.2022)	Shri Chottey Lal Kashyap	Gopramau, Malihabad	Lucknow	Uttar Pradesh	26°54'33.5"N 80°46'36.0"E
2	Safeda Amin (REG/2014/777 dated 26.09.2022)	Shri Amit	Mohammad Nagar, Malihabad	Lucknow	Uttar Pradesh	26°56'15.4"N 80°45'38.8"E
3	Matka Gola (REG/2014/780 dated 26.09.2022)	Shri Nawab Hasan	Kasmandi Kalan, Malihabad	Lucknow	Uttar Pradesh	26°55'40.0"N 80°46'22.2"E
4	Aamin (REG/2014/783 dated 26.09.2022)	Md. Shahdab	Kasmandi Kalan, Malihabad	Lucknow	Uttar Pradesh	26°56'22.7"N 80°46'05.9"E
5	Munjjar Aamin (REG/2014/784 dated 26.09.2022)	Md. Shahdab	Mohammad Nagar, Malihabad	Lucknow	Uttar Pradesh	26°55'02.7"N 80°46'09.6"E
6	Deshi Gola (REG/2014/807 dated 26.09.2022)	Shri Puttilal	Mohammad Nagar, Malihabad	Lucknow	Uttar Pradesh	26°56’25.8”N 80°45’32.9”E
7	August (REG/2014/775 dated 18.10.2022)	Shri Parmeshwar Deen	Mohammad Nagar, Malihabad	Lucknow	Uttar Pradesh	26°55'12.4"N 80°45'57.5"E
8	Jamun (REG/2014/779 dated 18.10.2022)	Shri Devendra Singh	Mohammad Nagar, Malihabad	Lucknow	Uttar Pradesh	26°56'11.0"N 80°45'44.5"E
9	Taimuriya (REG/2014/837 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°56'18.8"N 80°45'42.2"E
10	Gol Bhadaiyaan (REG/2014/839 dated 22.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°55'32.8"N 80°45'52.5"E
11	Aamin Khurd (REG/2014/841 dated 22.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'31.2"N 80°46'37.4"E
12	Markeara (REG/2014/846 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'33.1"N 80°46'37.1"E
13	Heere Hayat (REG/2014/847 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°56'29.2"N 80°45'30.3"E
14	Nayab (REG/2014/848 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'35.2"N 80°46'34.3"E
15	Gilas (REG/2014/851 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°57'49.0"N 80°47'47.5"E
16	Aamin Tehsil (REG/2014/853 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'35.8"N 80°46'36.8"E
17	Johri Safeda (REG/2014/855 dated 22.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°57'49.0"N 80°47'47.5"E

(*Contd*.)

Table 1 — List of indigenous mango germplasm and their corresponding source (*Contd*.)

S. No.	Mango Genotype, PPV&FRA Registration No. and Date	Farmers Name/ Community	Village/Tehsil	District	State	Latitude and Longitude
18	Aamin Abbasi (REG/2014/856 dated 22.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'36.6"N 80°46'33.0"E
19	Aamin Abdul Ahad Khan (REG/2014/857 dated 22.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'33.8"N 80°46'34.8"E
20	Lakhnawwa Safeda (REG/2014/858 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'36.9"N 80°46'35.0"E
21	Surraiya (REG/2014/860 dated 25.09.2023)	Malihabad Community	Malihabad	Lucknow	Uttar Pradesh	26°54'12.6"N 80°46'09.9"E

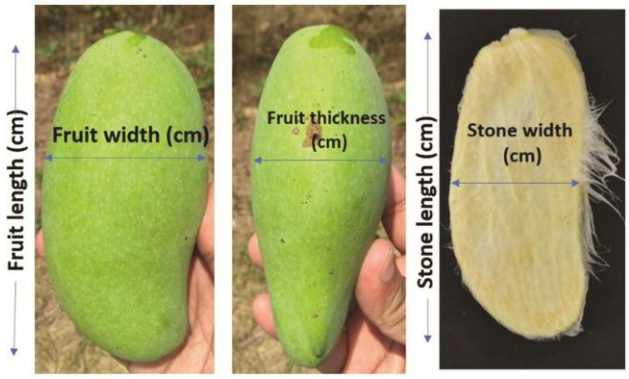


Fig. 2 — Representative photographs of fruit physical observations

The DUS descriptors for various characteristics of mango germplasm were studied *i.e.*, Inflorescence: time of flowering 50% of the tree, length (primary branch), width (secondary branch) and anthocyanin coloration of axis and branches; Mature fruit: length, width, shape in cross section, colour, density of lenticels, roughness of surface, presence of cavity at stalk, depth of cavity at stalk, presence of neck, shape of ventral shoulder, presence of groove in ventral shoulder, bulging on ventral shoulder, presence of sinus, depth of sinus and bulging proximal of stylar scar; Maturity: fruits ready to harvest; Ripe fruit: predominant colour of skin and main colour of flesh; Seed: kernel in lateral view and embryony.

Statistical analysis

Data was analysed using R studio. The Pearson's correlation study with significance levels set at p<-0.1, p<-0.5, 0.0, p>0.5, p>1.0 and ns>= 0.05; *p<0.05; **p<0.01; and ***p<0.001 was performed with significance level as significant, quite significant, and highly significant, respectively. Results significance of various physical and biochemical parameters of mango was assessed by One-way analysis of variance and post-hoc analysis using Duncan's multiple range tests ($p \leq 0.05$) using SPSS 16.0 (SPSS Corporation, Chicago, IL). To determine the indigenous mango germplasm fruit physical and biochemical variability Principal component analysis (PCA) was carried out by using MVPPE software.

Results and Discussion

Morphological traits of indigenous mango germplasm

In the present study the observations recorded on plant characteristics *viz*., inflorescence length (cm) and inflorescence width (cm), fruit weight (g), fruit volume (cc), fruit width (cm), fruit thickness (cm), peel weight (g), stone weight (g), stone length (cm), stone width (cm), kernel weight (g), pulp % and yield (kg/tree) (Table 2, 3 & Table 4). The differences in inflorescence length and breadth were significant and ranged from 12.43±2.09 to 30.53±4.07 cm and 7.18±0.82 to 16.1±1.53 cm, respectively. The Taimuriya genotype revealed highest plant panicle length and width. The variation in panicle size might be due to the response of traits to environmental conditions. Some researchers also reported that environmental conditions may be responsible for difference in panicle length and width[25-27].

The fruit weight ranged from 96.33±8.82 g (Gilas) to 854.33±67.8 g (Munjjar Aamin). Fruit volume varied from 110.63±4.49 cc to 897.33±67.53 cc, fruit length from 5.4±0.29 cm to 17.88±1.76 cm, fruit width from 4.68±0.1 cm to 9.45±0.25 cm, fruit thickness from 4.2±0.08 cm to 8.7±0.65 cm, peel weight from 18.58±1.54 g to 123.35±4.28 g, stone weight from 17.35±2 g to 82.4±3.54 g, stone length

Table 2 — Morphological traits of indigenous mango germplasm

Genotypes	Inflorescence: length (cm)	Inflorescence: width (cm)	Fruit weight (g)	Fruit volume (cc)	Fruit length (cm)	Fruit width (cm)	Fruit thickness (cm)
August	21.4±3.4^{defg}	15.15±0.44^{kl}	200.58±14.48^{efg}	210.6±14.45^{cdf}	10.88±0.7^{fg}	6.5±0.27^{def}	4.2±0.08^{a}
Tukhmi Heera	16.78±0.4^{bc}	8.6±0.5^{abcd}	209.18±13.28^{fgh}	220.33±9.53^{def}	9.8±0.34^{def}	6.7±0.61^{efg}	5.3±0.18^{defg}
Safeda Amin	25.63±1.7^{hi}	14.48±0.62^{jkl}	293.73±12.58^{j}	305.05±12.95^{h}	11.13±0.7^{g}	6.28±0.72^{bcdef}	5.28±0.36^{defg}
Jamun	26.1±0.82^{hi}	12.33±1.08^{fghi}	168.43±9.8^{cd}	178.45±8.56^{b}	9.68±0.43^{de}	5.85±0.57^{bcd}	4.95±0.24^{bcde}
Matka Gola	19.85±2.13^{cdef}	9.6±1.77^{bcdf}	451.1±25.48^{K}	433.1±27.03^{i}	8.9±0.72^{cd}	7.48±0.33^{h}	6.03±0.13^{ij}
Aamin	23.63±1.89^{ghi}	13.78±0.45^{ijk}	520±32.66^{l}	498.65±21^{j}	15.13±0.49^{h}	8.75±0.44^{i}	7.1±0.5^{k}
Munjjar Aamin	24.93±0.8^{ghi}	12.55±1.19^{ghij}	854.33±67.8^{m}	897.33±67.53^{k}	17.88±1.76^{i}	9.45±0.25^{j}	8.7±0.65^{l}
Deshi Gola	16.65±1.17^{bc}	8.2±0.95^{ab}	206.73±14.23^{fgh}	213.6±10.26^{cdf}	8.85±0.45^{cd}	6.35±0.31^{cdef}	5.73±0.28^{fgi}
Taimuriya	30.53±4.07^{j}	16.1±1.53^{l}	292.65±33.83^{j}	303±32.89^{h}	11.43±1.58^{g}	6.78±0.71^{fg}	5.85±0.9^{ghi}
Gol Bhadaiyaan	15±1.42^{ab}	7.7±1.12^{ab}	480.1±8.29^{k}	470.65±4.11^{j}	9.15±0.33^{cd}	7.23±0.37^{gh}	6.5±0.29^{j}
Aamin Khurd	25.75±3.59^{hi}	13.33±2.32^{hijk}	238.33±14.63^{hi}	263.43±11.93^{g}	10.63±0.22^{efg}	6.43±0.33^{cdef}	5.55±0.17^{efghi}
Markeara	12.43±2.09^{a}	8.25±1.64^{ab}	232±8.7^{ghi}	250.08±13.76^{fg}	8.45±0.17^{bc}	6.73±0.17^{efg}	5.93±0.1^{hij}
Heere Hayat	22.73±2.92^{fgh}	12.55±0.48^{ghij}	221.68±6.24^{ghi}	235.33±11.59^{efg}	10.48±0.26^{efg}	6.43±0.17^{cdef}	5.4±0.18^{efgh}
Nayab	18.65±2.2^{cde}	11.38±1.61^{efgh}	149.38±6.04^{bc}	165.63±6.96^{b}	7.45±0.29^{b}	5.78±0.46^{bc}	5±0.37^{bcde}
Gilas	12.73±1.42^{a}	7.18±0.82^{a}	96.33±8.82^{a}	110.63±4.49^{a}	5.4±0.29a	4.85±0.17^{a}	4.78±0.19^{abcd}
Aamin Tehsil	27.05±3.12^{i}	12.73±1.28^{hij}	250.6±4.36^{i}	259.43±9.8^{g}	10.55±0.6^{efg}	6.9±0.22^{fgh}	6.05±0.51^{ij}
Johri Safeda	19.63±1.89^{cdef}	8.45±1.33^{abc}	120.83±11.43^{ab}	132±10.06^{a}	8.18±0.36^{bc}	4.98±0.1^{a}	4.5±0.18^{ab}
Aamin Abbasi	21.7±2.38^{efg}	10.45±1.01^{cdfg}	120.58±7.12^{ac}	128.08±5.23^{a}	8.15±0.74^{bc}	4.98±0.32^{a}	4.6±0.14^{abc}
Aamin Abdul Ahad Khan	27.23±2.55^{i}	13.13±0.91^{hijk}	232.83±6.86^{ghi}	238±12.11^{efg}	11.23±0.72^{g}	6.08±0.74^{bcde}	5.95±0.66^{hij}
Lakhnawwa Safeda	17.88±2.24^{bcd}	10.55±2.81^{dfgh}	170.23±8.21^{cde}	184.93±5.32^{bc}	8.78±0.22^{cd}	5.65±0.26^{b}	5.15±0.17^{cdef}
Surraiya	13.18±2.12^{a}	8.6±0.14^{abc}	186.43±5.77^{def}	194±11.43^{bcd}	11.55±0.73^{g}	4.68±0.1^{a}	4.2±0.08^{a}

Values presented as means ± SD
Values in different columns in lowercase letters (small alphabet) indicates significantly different; $p<0.05$, Duncan's multiple range test between indigenous mango germplasm

Table 3 — Morphological traits and yield of indigenous mango germplasm

Genotypes	Peel wt (g)	Stone wt (g)	Stone length (cm)	Stone width (cm)	Stone thickness (cm)	Kernel wt (g)	Yield/tree (kg)
August	38.5±2.76^{defg}	32.58±4.02^{fg}	9.6±0.36^{ij}	5.4±0.26^{j}	1.8±0.08^{bcde}	41.05±0.81^{k}	103.18±6.82^{fghe}
Tukhmi Heera	35.45±2.14^{cdef}	30.68±1.89^{defg}	8.33±0.42^{fg}	5.8±0.64^{k}	1.95±0.13^{e}	47.5±1.69^{l}	112.86±6.76^{ij}
Safeda Amin	40.25±0.33^{defg}	50.88±3.03^{h}	9.65±0.42^{ij}	4.8±0.08^{hi}	1.85±0.13^{cde}	38.45±0.29^{j}	100.13±4.76^{fgh}
Jamun	33.83±1.36^{cd}	26.48±2.78^{cd}	8.5±0.5^{fgh}	4.35±0.21^{fgh}	1.88±0.1^{de}	42.18±0.68^{k}	110.36±5.96^{hij}
Matka Gola	63.85±15.96^{h}	65.08±4.8^{i}	6.3±0.34^{b}	4.43±0.17^{gh}	1.78±0.1^{abcde}	22.3±0.27^{f}	98.68±5.15^{efg}
Aamin	90.13±5.52j	71.68±3.11^{j}	12.55±0.33^{k}	4.63±0.15^{hi}	1.7±0.45^{abcde}	23.8±0.52^{g}	250.21±15.04^{i}
Munjjar Aamin	123.35±4.28^{k}	82.4±3.54^{k}	14.28±0.43^{l}	5.73±0.88^{k}	1.95±0.37^{e}	35.1±0.7^{i}	168.13±13.52^{k}
Deshi Gola	34.35±2.16^{cde}	29.03±3.75^{def}	7.48±0.45^{de}	4.98±0.46^{ij}	1.65±0.44^{abcde}	42.15±1.25^{k}	110.52±7.06^{hij}
Taimuriya	43.68±5.82^{g}	34.28±1.47^{g}	9.23±1.4^{hi}	3.4±0.08^{bcd}	1.73±0.17^{abcde}	53.45±1.25^{m}	115.7±13.58^{j}
Gol Bhadaiyaan	73.38±3.13^{i}	63.83±3.15^{i}	7.3±0.34^{cde}	3.88±0.17^{def}	1.9±0.08^{de}	15.65±0.21^{de}	112.24±1.77^{ij}
Aamin Khurd	36.48±7.55^{cdefg}	31.43±2.26^{efg}	8.65±0.21^{gh}	2.63±0.36^{a}	1.43±0.25^{a}	11.88±0.22^{b}	114.49±7.54^{ij}
Markeara	36.23±3.02^{cdefg}	27.63±2.01^{cdf}	7±0.22^{bcde}	3.65±0.13^{cde}	1.9±0.08^{de}	16.83±1.39^{e}	97.87±3.45^{efg}
Heere Hayat	35.23±0.78^{cdef}	31.15±1.66^{efg}	8.75±0.48^{gh}	4.05±0.31^{efg}	1.78±0.1^{abcde}	25.1±0.9^{h}	65.42±1.68^{ab}
Nayab	29.35±0.94^{bc}	23.88±0.95^{b}	6.23±0.4^{b}	2.98±0.6^{ab}	1.75±0.06^{abcde}	13.28±0.71^{c}	107.71±5.13^{ghij}
Gilas	18.58±1.54^{a}	17.35±2^{a}	4.45±0.17^{a}	2.68±0.1^{a}	1.73±0.1^{abcde}	5.83±1.03^{a}	88.59±8.34^{cde}
Aamin Tehsil	43.13±1.92^{fg}	30.3±1.41^{defg}	8.7±0.71^{gh}	3.38±0.21^{bcd}	1.55±0.13^{abcd}	13.73±1.01^{c}	82.72±1.18^{cd}
Johri Safeda	29.43±2.76^{bc}	22.38±1.64^{b}	6.8±0.14^{bcd}	2.95±0.31^{ab}	1.88±0.1^{de}	15.3±0.12^{d}	93.31±8.04^{def}

(*Contd*.)

Table 3 — Morphological traits and yield of indigenous mango germplasm (*Contd*.)

Genotypes	Peel wt (g)	Stone wt (g)	Stone length (cm)	Stone width (cm)	Stone thickness (cm)	Kernel wt (g)	Yield/tree (kg)
Aamin Abbasi	25±1.56^{ab}	21.23±2.53^{b}	6.5±0.62^{bc}	2.7±0.08^{a}	1.48±0.05^{ab}	11.7±0.47^{b}	80.28±4.49^{c}
Aamin Abdul Ahad Khan	42.05±4.34^{efg}	30.03±1.85^{defg}	8.98±0.71^{ghi}	2.68±0.1^{a}	1.58±0.1^{abcd}	11.95±0.83^{b}	56.57±1.32^{a}
Lakhnawwa Safeda	38.48±3.73^{defg}	33.03±3.56^{fg}	7.73±0.31^{ef}	3.33±0.1^{bc}	1.88±0.05^{de}	22.5±0.98^{e}	48.09±2.58^{a}
Surraiya	33.33±2.45^{cd}	27.13±2.19^{cdf}	10.3±0.81^{j}	2.68±0.22^{a}	1.5±0.39^{abc}	4.73±0.5^{a}	79.67±1.92^{c}

Values presented as means ± SD
Values in different columns in lowercase letters (small alphabet) indicates significantly different; p<0.05, Duncan's multiple range test between indigenous mango germplasm

Table 4 — Fruit biochemical traits of indigenous mango germplasm

Genotypes	Pulp (%)	T.S.S. (°B)	Acidity (%)	TSS: acid ratio	Ascorbic acid (mg/100 g)	Total carotenoid (mg/100 g)	Total phenols (mg/100 g)	Total sugar (%)	Reducing sugar (%)	Non-Reducing sugar (%)
August	64.55±2.12^{cde}	19.4±0.34^{ij}	0.2±0^{a}	106.93±6.36^{l}	25.4±1.02^{defg}	5.45±0.26^{cd}	85.13±4.4^{d}	16.03±0.19^{g}	6.5±0.52^{c}	9.5±0.42^{fg}
Tukhmi Heera	68.3±2.52^{defg}	18.95±0.68^{hi}	0.4±0de	51.7±3.16^{fgh}	25±1.33^{cdef}	4.45±0.55^{b}	51.13±11.32^{abc}	14.63±0.13^{d}	5.93±0.55^{bc}	8.7±0.42^{cde}
Safeda Amin	68.95±1.02^{efgh}	20.45±0.79^{kl}	0.3±0^{b}	60.9±1.78^{j}	26.03±2.34^{defg}	6.1±0.91de	44.78±11.83^{ab}	16.6±0.2^{h}	5.55±0.52^{ab}	11.08±0.46^{h}
Jamun	64.1±3.26^{cd}	18.3±1.23^{gh}	0.33±0.05^{bc}	54.68±7.09^{ghij}	28.5±3.6^{g}	6.65±0.26^{ef}	90.55±7.6^{de}	15.63±0.13^{e}	5.95±0.52^{bc}	9.7±0.42^{fg}
Matka Gola	71.3±4.36^{fghi}	16.6±0.45^{de}	0.4±0de	44.5±1.26^{cde}	24.33±1.92^{bcdef}	4.33±0.36^{cd}	92.9±15.92^{df}	18.1±0.14^{k}	5.9±0.52^{bc}	12.2±0.42^{ij}
Aamin	68.83±1.96^{efgh}	15.4±0.22^{c}	0.3±0^{b}	49.43±2.32^{efg}	22.65±2.44^{bcd}	5.65±0.19^{b}	63.45±8.1^{bc}	16.88±0.15^{i}	5.5±0.52^{ab}	11.4±0.42^{h}
Munjjar Aamin	75.83±2^{i}	19.25±0.37^{ij}	0.4±0de	46.88±1.47^{def}	32.15±2.89^{h}	7.25±0.58^{fg}	87.3±11.32^{d}	17.5±0.14^{j}	5.95±0.52^{bc}	11.55±0.48^{hi}
Deshi Gola	69.3±2.06^{fgh}	18.78±0.48^{hi}	0.33±0.05^{bc}	55.68±3.79^{ghij}	24.5±1.31^{bcdef}	5.3±0.2^{cd}	36.2±7.84^{a}	15.08±0.15^{e}	5.53±0.55^{ab}	9.55±0.48^{fg}
Taimuriya	73.25±1.33^{hi}	21.15±0.45^{m}	0.35±0.06^{bcd}	58.78±6.79^{ij}	23.43±1.81^{bcd}	10±0.18^{k}	53.45±23.24^{abc}	12.63±0.13^{i}	5.95±0.52^{bc}	6.7±0.42^{a}
Gol Bhadaiyaan	71.43±0.88^{fghi}	13.55±0.44^{a}	0.43±0.05^{e}	31.05±1.64^{a}	25.8±0.67^{defg}	8.68±0.76^{ij}	85.98±20.01^{d}	14.6±0.2^{j}	5.6±0.52^{ab}	9±0.42^{def}
Aamin Khurd	71.35±4.53^{fghi}	20.33±0.46^{k}l	0.4±0de	56.75±2.72^{hij}	32.6±4.08^{h}	4.28±0.31^{b}	111.83±10f	14.63±0.19^{d}	5.6±0.52^{ab}	9.05±0.44^{def}
Markeara	72.43±2.74^{ghi}	13.45±0.48^{a}	0.38±0.05^{cde}	36.7±2.91^{ab}	23.93±2.53^{bcde}	8.08±0.25^{hi}	64.93±4.76^{c}	15.6±0.2^{f}	5.55±0.52^{ab}	10.05±0.44^{g}
Heere Hayat	70.05±0.81^{fgh}	16.9±0.51^{ef}	0.38±0.05^{cde}	46.2±6.46^{cdef}	22±1.63^{bc}	6.6±0.14^{ef}	41.08±8.44^{a}	17.65±0.1^{j}	4.98±0.49^{a}	12.7±0.42^{j}
Nayab	64.35±1.79^{cd}	19.88±0.41^{jk}	0.38±0.05^{cde}	55.68±1.43^{ghij}	24.88±1.99^{bcdef}	8.68±0.68^{ij}	45.35±13.88^{abc}	14.08±0.15^{d}	5.6±0.52^{ab}	8.5±0.42^{cd}
Gilas	62.63±1.46^{c}	19.18±0.66^{hij}	0.38±0.05^{cde}	52.8±0.56^{fghi}	27.6±3.01^{fg}	5.25±0.19^{c}	39.7±1.28^{a}	16.65±0.17^{h}	5.73±0.55^{abc}	10.9±0.42^{h}
Aamin Tehsil	70.7±1.17^{fgh}	15.65±0.42^{c}	0.4±0de	39.88±2.89^{bc}	25.33±1.36^{cfefg}	5.63±0.54^{cd}	130.95±24.7^{g}	11.65±0.17^{a}	6.25±0.52^{bc}	5.4±0.49^{a}
Johri Safeda	56.8±5.76^{a}	15.8±0.67^{cd}	0.38±0.05cde	41.25±6.39^{bcd}	27.03±1.03^{efg}	6.58±0.86^{ef}	109.38±17.67^{ef}	14.08±0.15^{c}	5.93±0.55^{bc}	8.15±0.48^{b}
Aamin Abbasi	61.65±1.82^{bc}	14.43±0.88^{b}	0.4±0de	40.15±2.68^{bc}	21.5±1.19^{ab}	8.95±0.64^{j}	34.03±10.73^{a}	15.1±0.14^{e}	5.9±0.52^{bc}	9.23±0.45^{ef}
Aamin Abdul Ahad Khan	69.08±1.62^{efgh}	21.05±0.54^{m}	0.35±0.06bcd	59.45±7.06^{ij}	33.9±1.2^{h}	7.68±0.67^{gh}	87.3±3.08^{d}	17.68±0.15^{b}	5.55±0.52^{ab}	12.1±0.42^{ij}
Lakhnawwa Safeda	57.83±5.65^{ab}	16.93±0.41^{ef}	0.2±0a	75.13±4.16^{k}	27.73±1.4^{fg}	1.2±0.55^{a}	38±1.39^{a}	15.65±0.1^{f}	6.4±0.52^{bc}	9.23±0.45^{ef}
Surraiya	67.5±2.69^{def}	17.63±0.46^{gf}	0.35±0.06bcd	50.43±4.66^{efgh}	18.88±0.91^{a}	5.43±0.66^{cd}	92.2±6.89^{de}	15.08±0.15^{e}	5.95±0.52^{bc}	9.15±0.48^{def}

Values presented as means ± SD
Values in different columns in lowercase letters (small alphabet) indicates significantly different; p<0.05, Duncan's multiple range test between indigenous mango germplasm

from 4.45±0.17 cm to 14.28±0.43 cm, stone width from 2.68±0.1 cm to 5.73±0.88 cm, stone thickness from 1.43±0.25 cm to 1.95±0.13 cm, kernel weight from 4.73±0.5 g to 53.45±1.25 g. Munjjar Aamin had the maximum fruit weight, fruit volume, fruit length, fruit width, fruit thickness, peel weight, Stone weight, stone width, and stone thickness. In Mallika, higher pulp percentage is reported[28-31]. Higher fruit weight, length, breadth and volume were also observed in Mallika[32]. Fruit physical characterization of sixteen mango cultivars was carried out at RRS, Gayeshpur, West Bengal and wide variation was observed for fruit physical parameters[33]. Morphological and yield attributes of twelve mango cultivars were evaluated in western Uttar Pradesh and the highest yield was obtained in Mallika[34]. The photosynthetic efficiency, genetic character and fruit: stone ratio might be responsible for the differences in peel weight, fruit pulp percentage and stone weight. Fruits with higher pulp percentage are having better marketability and are very much required for the mango improvement program. Yield (250.21±15.04 kg/tree) was recorded highest in Aamin followed by Munjjar Aamin (168.13±13.52 kg/tree) and the lowest yield was noted in Lakhnawwa Safeda (48.09±2.58 kg/tree). The pulp percentage was highest (75.83±2%) in Munjjar Aamin whereas the lowest (56.8±5.76%) pulp percentage was recorded in Johri Safeda (Table 4). The variations in fruit yield may be due to the several factors especially genetic potential of the particular genotype

and their adaptability to the specific environmental conditions.

Biochemical traits of indigenous mango germplasm

Indigenous mango germplasm exhibited noteworthy variances in biochemical attributes *viz.*, TSS, acidity, ascorbic acid, TSS and acid ratio, total phenols, total carotenoids, total sugar, reducing sugar and non-reducing sugar. TSS of indigenous mango germplasm ranged from 13.45±0.48 to 21.15±0.45 °B. Highest TSS content (21.15±0.45 °B) was observed in Taimuriya followed by Aamin Abdul Ahad Khan (21.05±0.54 °B) and lowest TSS content was found in Markeara (13.45±0.48 °B) (Table 4). Natural fruits are a nutritious option for people generally living in rural areas[35]. In Amrapali, non-reducing sugar (14.62%), total sugars (20.69%) and TSS (22.32°Brix) was also reported higher than other hybrids[29]. Fifty mango genotypes were analysed for biochemical compounds and result reveals high genetic diversity exists in mango gene pool[36]. The acidity was recorded highest in Gol Bhadaiyaan (0.43±0.05%), lowest in August and Lakhnawwa Safeda (0.2±0%). The TSS: acid ratio ranged from 31.05±1.64 to 106.93±6.36) in indigenous mango germplasm. The highest TSS: acid ratio was recorded in August (106.93±6.36). The variations in TSS: acid ratio among the several mango genotypes was observed by various researchers[30,31]. Genotypic characters and prevailing weather conditions are the major factors affecting the fruit acidity conditions especially during the fruit developmental stages. TSS: Acid ratio is most important parameter for incorporating the exceptional flavour and taste of mango germplasm.

Ascorbic acid content varied significantly among the indigenous mango germplasm. Highest ascorbic acid content (33.9±1.2 mg/100 g) was recorded in Aamin Abdul Ahad Khan followed by Munjjar Aamin (32.15±2.89 mg/100 g). Surraiya (18.88±0.91 mg/100 g) revealed the lowest ascorbic acid content. In a study, Langra showed highest ascorbic acid content (55.62 mg/100 g) trailed by Pusa Arunima and Pusa Surya (45.63 mg/100 g and 46.25 mg/100 g, respectively)[31]. Ascorbic acid performances as a potential antioxidant and help the body against oxidative stress-related situation was reported[32]. Several pre-harvest factors, environment and genotypic interactions significantly contributein the variations in the ascorbic acid content of the indigenous mango germplasm[32].

Total carotenoids and total phenol content also varied significantly in indigenous mango germplasm. The highest total carotenoids were noted in Taimuriya (10±0.18 mg/100 g), and the lowest was in Lakhnawwa Safeda (1.2±0.55 mg/100 g). Total carotenoids contents are dependent on mango genotype, topographical location, and fruit maturity stage[12]. The carotenoids are closely linked with the ripening stage of fruit. The carotenoids are having nutraceutical properties and are playing vital role in the well-being of larger populations. Ripened mango fruit and pulp colour is also due the presence of carotenoids. Aamin Tehsil had the highest total phenols (130.95±24.7 g/100 g GAE), followed by Aamin Khurd (111.83±10f g/100 g GAE), with the lowest in Aamin Abbasi (34.03±10.73 g/100 g GAE). Similarly, in mango fruits study, total phenols content ranged between 23.66 and 56.15 mg/100 g[37]. The total phenol content which significantly enhances the fruit quality varied significantly (32.06-139.71 mg/100 g) in mango fruits[38,39]. The nutraceutical rich mango is important for food industry for production of functional foods and nutraceutical rich mango products[40].

Matka Gola exhibited the highest total sugar (18.1±0.14%). While minimum total sugar content was recorded in Aamin tehsil. Higher total sugars were recorded in Keitt mango, however, higher TSS level was inconsistent[37]. The non-reducing and total sugar content variations was observed with the stage of ripening in different mango genotypes[41] and it ranged from 8.32 to 14.62% and 11.36 to 20.69%, respectively. The erstwhile researchers[42,43] reported that total sugars are increasing with the stage of fruit ripening in mature fruits because hydrolysing enzymes are converting starch and polysaccharides into soluble sugars. Recent reports[44] revealed that the total sugar levels in 30 days after fruit set can increase up to 4.48-6.52%, after 60 days it can raise up to 9.33-12.05% and 90 days after fruit set it may reach 16.89-20.01%.

Correlation studies on morphological and biochemical traits

Morphological and biochemical traits correlation studies have shown the deep interrelationships (Table 5 and Fig. 3). Positive Pearson's correlation coefficient of fruit weight (0.992) was observed with different fruit parameters *viz.*, yield (0.107), fruit length (0.710), fruit width (0.843), weight of kernel (0.382), pulp percentage (0.337), TSS (0.550), acidity (0.375) and total sugars (0.951). However, ascorbic

Table 5 — Correlation between morphological and biochemical attributes of indigenous mango germplasm

SN		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Inflorescence: Length (cm)	1.00	0.79	0.22	0.22	0.44	0.29	0.22	0.18	0.42	0.05	0.35	0.22	0.16	0.39	-0.04	0.16	0.33	0.20	0.25	-0.09	-0.04	-0.07
2	Inflorescence: Width (cm)		1.00	0.19	0.20	0.47	0.29	0.19	0.18	0.48	0.14	0.38	0.26	0.22	0.46	-0.27	0.45	0.20	0.14	0.12	-0.01	-0.05	0.01
3	Fruit weight (g)			1.00	0.99	0.75	0.86	0.97	0.93	0.67	0.49	0.20	0.60	0.63	-0.06	0.17	-0.21	0.20	0.10	0.20	0.33	-0.05	0.32
4	Fruit volume (cc)				1.00	0.77	0.85	0.96	0.91	0.68	0.49	0.21	0.59	0.61	-0.03	0.18	-0.20	0.23	0.11	0.21	0.33	-0.05	0.31
5	Fruit length (cm)					1.00	0.71	0.77	0.68	0.95	0.45	0.30	0.48	0.59	0.17	-0.10	0.07	0.16	0.05	0.22	0.23	0.03	0.20
6	Fruit width (cm)						1.00	0.84	0.83	0.64	0.61	0.35	0.60	0.68	-0.05	0.07	-0.09	0.19	0.05	0.12	0.23	-0.05	0.23
7	Peel wt. (g)							1.00	0.92	0.69	0.48	0.17	0.44	0.66	-0.11	0.10	-0.17	0.20	0.08	0.22	0.32	-0.01	0.29
8	Stone wt. (g)								1.00	0.60	0.52	0.20	0.45	0.63	-0.12	0.06	-0.16	0.12	-0.01	0.14	0.40	-0.02	0.37
9	Stone length (cm)									1.00	0.44	0.33	0.41	0.56	0.19	-0.17	0.14	0.11	0.00	0.18	0.19	0.06	0.16
10	Stone width (cm)										1.00	0.73	0.31	0.44	0.10	-0.16	0.22	-0.01	-0.16	-0.13	0.28	0.03	0.24
11	Kernal wt. (g)											1.00	0.22	0.26	0.38	-0.28	0.37	-0.01	0.03	-0.23	-0.03	0.08	-0.05
12	Pulp %												1.00	0.34	0.12	0.34	-0.23	0.06	0.23	0.17	0.08	-0.31	0.17
13	Fruit yield per Tree													1.00	-0.05	0.02	-0.10	-0.01	0.10	0.05	0.11	-0.10	0.13
14	T.S.S. (°B)														1.00	-0.19	0.55	0.42	-0.06	-0.10	0.08	-0.03	0.08
15	Acidity (%)															1.00	-0.77	0.01	0.38	0.20	-0.15	-0.22	-0.06
16	TSS acid ratio																1.00	0.16	-0.34	-0.12	0.13	0.26	0.03
17	Ascorbic acid (mg/100 mL)																	1.00	-0.11	0.27	0.18	0.02	0.15
18	Total carotenoid (mg/100 g)																		1.00	-0.05	-0.20	-0.15	-0.13
19	Total phenols (mg /100 g)																			1.00	-0.22	0.17	-0.25
20	Total sugar (%)																				1.00	-0.16	0.95
21	Reducing sugar (%)																					1.00	-0.46
22	Non- reducing sugar (%)																						1.00

Correlation significant at the 0.05 level

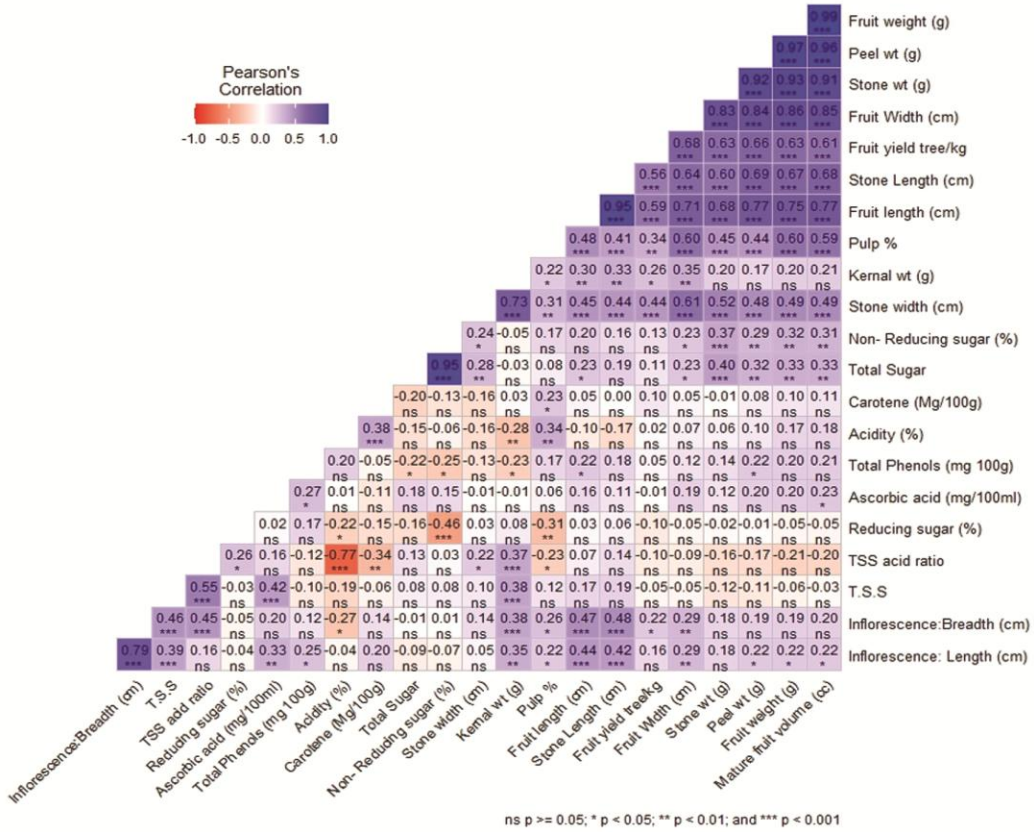


Fig. 3 — Pearsons's correlation for morphological and biochemical traits of indigenous mango germplasm

acid (-0.114) and total phenol content (-0.250) were negatively correlated. Yield correlated positively with ascorbic acid (0.269), total phenols (0.172), TSS acid ratio (0.256), and acidity (0.375), however, yield exhibited negative correlation with carotene (-0.204) content and reducing sugars (-0.459).

Cluster analysis

Morphological and biochemical parameters-based cluster analysis of 21 indigenous mango germplasm exposed primary groups when envisioned using a dendrogram (Fig. 4). Group I consisted of genotypes, Munjjar Aamin and Aamin which displayed distinct profiles in both morphological and biochemical traits, setting them apart from the other genotypes in the study. Group II encompassed the remaining nineteen genotypes and were further divided into subgroups. The first subgroup included Surraiya, Aamin Abbasi, Gilas, Nayab, Johri Safeda and Safeda Aamin. The second subgroup included Heere Hayat, Deshi Gola, Markeara, Gol Bhadaiyaan and Matka Gola. The third subgroup included Aamin Abdul Ahad Khan, Aamin Khurd, Aamin Tehsilwala. The fourth subgroup included Taimuriya, August, Tukhmi Heera, Jamun etc. These genotypes shared close similarities, suggesting common underlying morphological and biochemical characteristics. This similarity may be due to genetic or environmental factors affecting these traits. In contrast, Group I consisted of a Munjjar Aamin and Aamin, which exhibited unique characteristics that distinguished them from the other indigenous mango germplasm within this cluster (Fig. 4). The better fruit yield, higher TSS, ascorbic acid content, total sugars, reducing sugar and phenol content positioned Munjjar Aamin and Aamin as superior type over all other mango germplasms. This distinction suggests that Munjjar Aamin and Aamin may possess specific traits or adaptations that are less common among the other genotypes.

Principal Component Analysis (PCA)

The PCA analysis was carried out to identify mango genetic diversity based on fruit and biochemical traits (Fig. 5). On the basis of quantitative data of fruit characters (Supplementary Table S2 and S3), the PCA categorized the genotypes into two major clusters. PCA revealed that comp 1 and comp 2 covered 35.1% and 13.4% of the total variability, highlighting traits such as, Peel weight, Fruit volume and Fruit weight, with respective maximum value of 10.34, 10.58 and 10.69. These findings indicate that these traits contribute significantly to the genetic diversity and have potential to utilize for the improvement of mango genotypes. Comp 2 appeared as a dominant component, elucidating 48.50% variability for peel weight (10.349), explaining peel weight is highly variable amid the indigenous mango germplasm. Additionally, 57.488% and 64.896% of total variability was recorded in comp 3 and comp 4, respectively. Comp 3 significantly contributing for fruit yield trait. In PCA analysis, distinct patterns were observed for the diversity of morphological and biochemical traits between the indigenous mango germplasm. Genetic variation understanding for fruit characters and their heritability is essential in mango which is a highly heterozygous in nature[45].

Fig. 4 — Dendrogram analysis of indigenous mango germplasm for morpho-biochemical traits

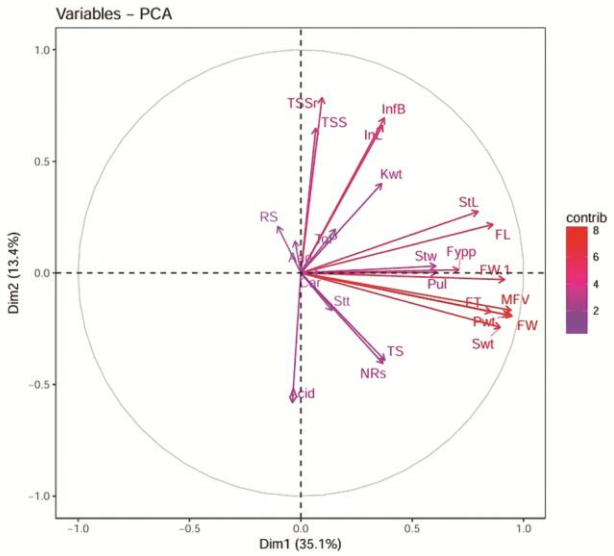


Fig. 5 — Variable PCA of indigenous mango germplasm for morpho-biochemical traits

Conclusion

This study identified and documented the novel high-yielding indigenous mango germplasm for subtropical conditions, also revealed diverse biochemical trait profiles across the indigenous mango germplasm. The study further highlighted key trait correlations for breeding, and provided insights for developing high-quality mango varieties in future. To the best of our knowledge this is the first study to document the various traits of indigenous mango germplasm of Malihabad region. The study revealed substantial genetic diversity among the indigenous mango germplasm in the Malihabad region of Lucknow, Uttar Pradesh. Assessment of the mango germplasm for various morpho-biochemical traits reveals the potential of indigenous mangos for different traits and unique qualities. The better fruit yield, higher TSS, ascorbic acid content, total sugars, reducing sugar and phenol content positioned Munjjar Aamin and Aamin as superior type over all other mango germplasms. This distinction suggests that Munjjar Aamin and Aamin may possess specific traits or adaptations that are less common among the other genotypes. Cluster and Principal Component analysis recognized wide-ranging differences in morphological and biochemical traits emphasizing the opportunity to develop mango varieties suitable for subtropical conditions with higher yield and better fruit quality. This study also facilitates the selection of suitable indigenous mango germplasm which are acclimatized to the subtropical climatic conditions having better or at par yield and quality with the commercial mango cultivars. Documentation of unique qualities and commercial potential will also help in conservation of indigenous mango germplasm of Malihabad region, Lucknow Uttar Pradesh. This research finds promising indigenous mangos of Malihabad region that can be commercially multiplied for large scale cultivation in subtropical regions and further used in breeding for the development of climate-resilient mango varieties having improved fruit quality and higher productivity.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at https://nopr.niscpr.res.in/jinfo/ijtk/IJTK_24(10)(2025)966-979_SupplData.pdf

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Conflict of Interest

All the authors declare that they have no competing interests.

Author Contributions

VS, AY, VD: conceptualization, methodology, investigation, data curation formal analysis, writing of original draft. SK, SNS, AKK: Writing-review & editing. SR and TD: investigation and resources.

Data Availability

Data related to present work made available in this paper as well as in supplementary tables.

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