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RESEARCH ARTICLE

Elucidating Diversity among Mango (*Mangifera indica* L.) Hybrids based on Morphological Characters using DUS Guidelines

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Abstract

Mango (*Mangifera indica* L.) is adored by people owing to its delicious taste, aroma, sugar acid blend, attractive fruit and nutritional value. In the present investigation, genetic diversity among 24 mango hybrids bred at ICAR- Indian Agricultural Research Institute was observed using 11 quantitative and 16 qualitative traits as per the DUS guidelines on mango. Hybrids showed significant differences for leaf, inflorescence, panicle and fruit attributes. The maximum leaf area was recorded in H-4-8 (101.99 cm^2) and only two categories of leaf blade shapes were observed among hybrids. Most of the hybrids (91.6%) showed the presence of twisting leaf blade except H-3-2 and H-4-8. Pusa Manohari had the maximum anthocyanin coloration of rachis. Pusa Pratibha bloomed earliest, whereas Pusa Lalima showed earliest fruit maturity among hybrids. The maximum fruit weight and length (336.44 g, 14.56 cm) were observed in Mallika. Petiole length, leaf area, leaf blade length, leaf blade width and inflorescence width were recorded as highly diverse traits among mango hybrids. Results indicated that four superior hybrids, *viz*., H-4-8, NH-17-4, NH-18-4 and Pusa Arunima depicted strong peel chrominance which was majorly associated with export markets and consumer acceptance. The UPGMA dendrogram based on K–clustering grouped mango hybrids in to two major clusters. DUS fingerprint was generated using 16 qualitative traits. These would be helpful in the identification of these hybrids precisely. The information generated in the present study has significance in the conservation, cultivar improvement, protection and utilization of mango hybrids in future.

Keywords: Clustering, DUS guidelines, Fingerprint, Hybrids, *Mangifera indica*, Mango.

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Introduction

Mango (*Mangifera indica* L.) a member of the family Anacardiaceae, is acclaimed as national fruit crop in India, and is grown in a wide range of tropical and sub-tropical climates all over the world. Mango production in the world is projected to exceed 55.38 million MT, and India as the top mango producer in the world produces 20.44 million MT of mangoes from an area of 2.29 million ha (NHB, 2019-20). India offers a huge export potential for this fruit and exported about 27,872.06 MT of fresh mango valuing 327.42 crore (APEDA, 2021-22). Though India is the largest producer of the choicest varieties of mango, its share in the international market is abysmally low. In India, there are over a thousand different mango varieties (Mukherjee, 1951). Despite having so much diversity for this fruit crop in our country, only a dozen are under commercial cultivation. Most of these varieties have one or other defects like poor shelf-life, spongy tissue, mango malformation and alternate bearing.

In India, mango improvement work was initiated in the year 1911 at Pune, Maharashtra (Burns and Prayag, 1921) but has not been pursued after to yield any useful information. Later, at the ICAR-Indian Agricultural Research Institute (ICAR-IARI), New

Delhi, systematic hybridization work was started in 1961, which resulted in the development of two regular bearing popular hybrids, namely, Mallika (Neelum x Dashehari) and Amrapali (Dashehari x Neelum) (Singh *et al.,* 1972). The emphasis later shifted towards developing red peel-colored mango cultivars targeting overseas markets. This led to the development and release of a series of improved mango cultivars with red peel and good fruit quality, namely, Pusa Arunima in 2002, and Pusa Pratibha, Pusa Shrestha, Pusa Peetamber and Pusa Lalima hybrid varieties in 2012, which have been released by central variety release committee for commercial cultivation at national level in 2021. In 2021, two more mango hybrids, Pusa Deepshikha and Pusa Manohari, were released by the Delhi State Seed Sub-committee for commercial cultivation in the National Capital Region. At ICAR-IARI, New Delhi mango hybridization work is in progress and several hundred hybrids obtained from different cross combinations have been evaluated. Characterization of these hybrids using DUS guidelines is of utmost importance to safeguard the protection of these valuable mango hybrids. DUS Testing is the standard process of evaluating plant varieties for distinctiveness, uniformity, and stability. Bhamini *et al.* (2018) illustrated the significance of DUS Descriptor developed by PPV & FR, 2001 and marked its esteemed importance in diversity analysis studies. The stable plant characteristics that are unaffected by the environment are often taken into consideration during DUS characterization. The present study aimed to characterize mango hybrids bred at ICAR- IARI, New Delhi based on DUS guidelines, which would help in varietal identification, protection and resolve intellectual property rights issues. The information gained in the present investigation will also be useful for selecting desirable traits to develop superior hybrids.

Material and Methods

Plant Material

In 24 mango hybrids, bred at the ICAR- IARI, New Delhi aged 10 to 20 years were selected for the studies (Table 1). These mango hybrids have been maintained under uniform cultural practices during the period of investigation.

Morphological Analysis

Mango hybrids were characterized for leaf, inflorescence and fruit parameters based on standard DUS guidelines on mango (PPV & FRA)-2020 and Mango Descriptor, IPGRI, Rome Italy. Twenty- seven (11 quantitative and 16 qualitative) traits representing leaf, inflorescence and fruits were studied over two years. The experiment followed a randomized block design. The morphological traits were assessed using 10 replications from relevant parts taken from each plant. Mature leaves were taken from the middle third portion of young shoot. The leaf blade length, width, and area were measured with WinFOLIA™ software using leaf area meter (*REGENT*, Canada). Petiole length was measured using a digital Vernier Caliper (Mitutoya Model 500-147). Mango hybrids were categorized into early, medium and late groups based on the time of 50% flowering on the tree. The inflorescence length and inflorescence width were measured using a measuring scale. Fruits were harvested at mature firm stage based on standard maturity criterion and ripened at ambient temperature. Fruit length and width was measured using a digital Vernier calliper. Fruit weight was measured with the help of digital electronic balance (Adiar Dutt-1620C, USA). Intensity of anthocyanin pigmentation, leaf blade shape, leaf color, twisting of leaf blade, shape of leaf base, the shape of leaf apex, anthocyanin coloration of rachis, shape of mature fruit, color of mature fruit, presence of cavity at stalk, fruit beak type, sinus type, depth of sinus and maturity of fruits were observed based on categories given in mango DUS guidelines and descriptor.

Cluster Analysis and DUS Fingerprinting

The UPGMA clustering and principal component analysis (PCA) was carried out using IBM SPSS Statistics ver. 26 software. A fingerprint of 24 mango hybrids based on horticultural traits mentioned in DUS guidelines has also been generated using Microsoft Excel 2019.

Results

Characterization Based on Quantitative Traits

In the present investigation, significant variations were observed for the majority of quantitative traits. Leaf blade length ranged from 14.87 cm (Pusa Pratibha) to 24.70 cm (H-4-8), and leaf blade width varied from 3.87 cm (NH-19-2) to 5.83 cm (H-4-8). Significant variation was also evident for petiole length, and mango hybrids grouped into two categories based on medium and long petiole types (Table 2). Leaf area ranged from 45.99 to 101.99 cm^2, and significant varied among hybrids. The maximum (101.99 cm^2) leaf area was in H-4-8 and the minimum (45.99 cm^2) was in Pusa Pratibha. The data showed significantly variation for inflorescence length and it ranged from 18.11 to 46.58 cm among hybrids. The maximum inflorescence length (46.58 cm) was observed in H-7-1 followed by Pusa Lalima (41.91 cm) and H-3-2 (37.42 cm), while the minimum was recorded in NH-20-2 (18.11 cm), NH-17-3 (19.51 cm) and Pusa Peetamber (22.56 cm), respectively. Similarly, inflorescence width among hybrids varied from 8.50 to 12.42 cm. The minimum inflorescence width was noted in H-12-5 (8.50 cm) followed by NH-20-2 (8.85 cm) and H-4-8 (8.91 cm). A significant level of variation was also noted for the fruit length among mango hybrids. The maximum fruit length was noted in Mallika (14.56 cm) while it was minimum (7.56 cm) in NH-17-3. The fruit width was maximum (7.60 cm) in Mallika and minimum (4.38 cm)

Table 1: List of mango (*Mangifera indica* L.) hybrids used in the present study

Sr. No.	*Hybrid*		*Parentage*
1	Amrapali	:	Dashehari x Neelum
2	H-1-11	:	Amrapali x Sensation
3	H-12-5	:	Amrapali x Sensation
4	H-1-5	:	Amrapali x Sensation
5	H-2-14	:	Amrapali x Alphanso
6	H-3-2	:	Amrapali x Sensation
7	H-4-8	:	Amrapali x Sensation
8	H-7-1	:	Amrapali x Sensation
9	Mallika	:	Neelum x Dashehari
10	NH-16-2	:	Amrapali x Sensation
11	NH-17-1	:	Amrapali x Sensation
12	NH-17-3	:	Amrapali x Sensation
13	NH-17-4	:	Amrapali x Sensation
14	NH-18-4	:	Amrapali x Sensation
15	NH-19-2	:	Amrapali x Sensation
16	NH-19-3	:	Amrapali x Sensation
17	NH-20-2	:	Amrapali x Sensation
18	Pusa Arunima	:	Amrapali x Sensation
19	Pusa Deepshikha	:	Amrapali x Sensation
20	Pusa Lalima	:	Dashehari x Sensation
21	Pusa Manohari	:	Amrapali x Lal Sundari
22	Pusa Peetamber	:	Amrapali x Lal Sundari
23	Pusa Pratibha	:	Amrapali x Sensation
24	Pusa Shreshth	:	Amrapali x Sensation

H-hybrid, NH- New hybrids

in NH-17-4. Among hybrids, fruit shape index ranged from 1.40 to 2.33, indicating oblong to roundish fruits. A perusal of data indicates that there was a wide range of variation for fruit weight among mango hybrids and varied from 94.87 to 336.44 g. The maximum fruit weight (336.44 g) was recorded in Mallika, followed by Pusa Deepshikha (276.35 g) while the minimum fruit weight (94.87 g) was observed in NH-19-2 followed by NH-17-4 (99.31 g).

Morphological Characterization Based on Qualitative Traits

In the present study, 16 qualitative traits were included to characterize 24 mango hybrids. The distribution of each trait was found to be polymorphic among hybrids. Among 24 mango hybrids, only two categories of leaf blade shapes were observed (i) elliptic (96%) and (ii) oblong (4%). Most of the mango hybrids showed the presence of twisting leaf blade (91.6%). The majority of hybrids were observed with an acute (96%) type leaf base shape. However, NH-17-1 had an obtuse type of leaf base. Out of the 24 mango hybrids, 18 hybrids (75%) had an attenuate type of leaf apex shape, and the remaining 6 hybrids (25%) were observed with an acuminate type of leaf apex. Two types of leaf color, including light green (12%) and dark green (88%) were observed. Out of 24 hybrids, only three classes of leaf anthocyanin intensity were recorded, *i.e.*, weak (25%), medium (46%) and strong (29%). Flowering-related traits, including anthocyanin coloration of rachis and time of 50% flowering, were observed. It was evident that 45.8% of mango hybrids had medium type of coloration on rachis, and most of mango hybrids (50%) were recorded with weak or absence of anthocyanin coloration of rachis. Pusa Manohari was the only hybrid to have a strong anthocyanin coloration of rachis. Among 24 mango hybrids, Pusa Pratibha was found to have the earliest initiation of flowering. Observation on mature fruit color revealed that eight hybrids (33.33%) had green and yellow peel color, whereas seven hybrids (29.16%) had green and orange peel color, four hybrids (16.66%) had green and pink peel color, four hybrids (16.66%) with green and purple peel color and only one hybrid observed to have only green coloration for fruit peel, and highest diversity index (1.45) in mature fruit color trait was observed (Table 3). Most of the mango hybrids (71%) did not have a cavity at the fruit stalk, and only seven hybrids (29%) had shallow cavity at the fruit stalk. The prominence of fruit beak was observed as a significant attribute that influences customer acceptability and marketing of mango fruits. Out of 24 mango hybrids, 50% of hybrids had a perceptible beak. Whereas 12.50% of hybrids registered a pointed type of beak and 37.50% of hybrids were observed with a prominent type of beak. Noticeable variations for the fruit sinus were also observed and 70.83% of hybrids had sinuses and 29.16% of the hybrids without sinus. The majority of hybrids (70.83%) had shallow sinuses and (29.16%) of hybrids had no sinuses. Overall, 66.66% of hybrids had oblong, 16.66% were obovoid, 8.33% roundish and 8.33% with ovoid fruit shapes were observed. Results pertaining to fruit maturity indicated that the earliest fruit maturity was observed only in Pusa Lalima and 11 hybrids had medium maturity. In contrast, 12 hybrids were found to be of late maturity group.

Cluster Analysis Based on Morphological Traits

Cluster analysis of mango hybrids was carried out based on the observations on morphological parameters studied. Two-step hierarchical clustering and K-mean cluster analysis were used using IBM SPSS Statistics ver. 26 software. K–clustering offered more stable results when compared to hierarchical clustering. Cluster membership indicated that 24 hybrids were categorized into two major clusters. Cluster I included maximum number of mango hybrids (17) comprising Amrapali, H-12-5, H-1-5, H-2-14, Mallika, NH-16-2, NH-17-1, NH-17-3, NH-17-4, NH-19-2, NH-19-3, NH-20-2,

Table 2: Morphological characterization of different mango hybrids based on DUS guidelines

Hybrid	*Leaf blade length*	*Leaf blade width*	*Petiole length*	*Leaf blade shape*	*Twisting of leaf blade*	*Shape of leaf base*	*Shape of leaf apex*	*Leaf colour*	*Leaf anthocyanin colouration*	*Inflore-scence length*	*Inflore-scence width*
Amrapali	5	5	5	5	9	3	5	7	5	5	7
H-1-11	5	5	7	5	9	3	3	7	5	7	7
H-12-5	5	5	5	5	9	3	5	3	7	5	5
H-1-5	5	5	5	5	9	3	3	7	5	5	5
H-2-14	5	5	7	5	9	3	3	7	3	7	7
H-3-2	7	5	5	7	1	3	5	7	5	7	7
H-4-8	7	5	5	5	1	3	3	7	5	5	5
H-7-1	5	5	5	5	9	3	3	7	3	7	7
Mallika	5	5	5	5	9	3	3	3	5	7	7
NH-16-2	5	5	5	5	9	3	3	7	3	7	7
NH-17-1	5	5	7	5	9	5	5	3	7	7	5
NH-17-3	5	5	7	5	9	3	3	7	3	3	7
NH-17-4	5	5	5	5	9	3	3	7	5	7	7
NH-18-4	5	5	5	5	9	3	5	7	3	5	5
NH-19-2	5	5	7	5	9	3	3	7	5	5	5
NH-19-3	5	5	7	5	9	3	3	7	7	5	7
NH-20-2	5	5	7	5	9	3	3	7	7	3	5
Pusa Arunima	5	5	5	5	9	3	3	7	5	5	7
Pusa Deepshikha	5	5	5	5	9	3	3	7	7	7	7
Pusa Lalima	5	5	5	5	9	3	3	7	5	7	7
Pusa Manohari	5	5	7	5	9	3	5	7	5	5	5
Pusa Peetamber	7	5	7	5	9	3	3	7	7	5	7
Pusa Pratibha	5	5	5	5	9	3	3	7	7	5	7
Pusa Shreshth	5	5	5	5	9	3	3	7	3	7	7

Leaf blade length (3- short (<12 cm), 5- medium (12-22 cm) and long (>22 cm); Leaf blade width (3- narrow (<3 cm), 5- medium (3-6 cm) and 7-broad (>6 cm); Petiole length (3- short (<1.5 cm), 5- medium (1.5-3.0 cm) and 7- long (>3 cm; Leaf blade shape (3-ovate, 5- elliptic, 7- oblong); Twisting of leaf blade (1- absent, 9- Present); Shape of leaf base (3- acute, 5- obtuse, 7- rounded); Shape of leaf apex (3- attenuate, 5- acuminate, 7- acute); Leaf colour (3- light green, 7- dark green);Young leaf: intensity of leaf anthocyanin (1- absent, 3- weak, 5- medium, 7- strong); Inflorescence length (3- short (<20 cm), 5- medium (20-30 cm) and 7- long (>30 cm); Inflorescence width (3- short (<7.5 cm), 5- medium (7.5-15 cm) and 7- long (>15 cm)

Pusa Arunima, Pusa Lalima, Pusa Manohari, Pusa Pratibha and Pusa Shreshth while, cluster II comprised of remaining seven hybrids, viz., H-1-11, H-3-2, H-4-8, H-7-1, NH-18-4, Pusa Deepshikha and Pusa Peetamber (Figure 1). ANOVA based on K–clustering showed that out of 23 traits, 5 traits *viz*. twisting of leaf blade, fruit sinus type, depth of sinus, mature fruit shape and leaf blade length were found to be significant across the two clusters.

DUS Fingerprints of Mango Hybrids

DUS fingerprints of mango hybrids have been considered important horticultural traits for the conduct of test for distinctiveness, uniformity and stability on mango and presented in Table 4. The fingerprints include 14 morphological informative traits representing 24 mango hybrids. Different color codes were given for traits showing variation for each character and similar kind of pattern was also followed in 24 mango hybrids. Identification of these mango hybrids at particular crop growth phases could be made easier using these DUS fingerprints. It was found that three characters, *viz*., leaf blade shape, shape of leaf base and time of 50% flowering, were highly informative among all characters for the mango hybrids, namely, H-3-2, NH-17-1 and Pusa Pratibha.

Discussion

The present demand of trait-specific varieties has resulted in a shift of mango breeding objectives to develop more

Table 2. Cont: Morphological characterization of different mango hybrids based on DUS guidelines

Hybrid	*Anthocyanin colouration of rachis*	*Time of flowering: 50% of tree*	*Fruit length*	*Fruit width*	*Mature fruit colour*	*Presence of cavity at stalk*	*Depth of cavity at stalk*	*Fruit sinus type*	*Depth of sinus*	*Fruit beak type*	*Mature fruit shape*	*Maturity group: Fruits ready to harvest*
Amrapali	3	5	5	5	3	1	1	1	1	1	1	7
H-1-11	1	5	7	5	3	9	3	9	3	3	5	5
H-12-5	1	5	5	5	5	1	1	1	1	1	5	5
H-1-5	3	5	7	5	3	1	1	9	3	1	1	7
H-2-14	3	5	5	5	5	1	1	1	1	1	1	5
H-3-2	3	5	7	5	3	9	3	9	3	2	5	7
H-4-8	1	5	5	5	9	9	3	9	3	3	1	7
H-7-1	1	5	5	5	3	9	3	9	3	3	2	5
Mallika	1	5	7	7	5	1	1	9	3	2	1	5
NH-16-2	1	5	5	5	1	1	1	9	3	1	1	5
NH-17-1	1	5	5	3	3	1	1	1	1	1	1	7
NH-17-3	1	5	5	5	3	1	1	9	3	1	1	7
NH-17-4	1	5	7	3	9	1	1	9	3	3	1	7
NH-18-4	3	5	5	5	9	9	3	9	3	2	5	7
NH-19-2	3	5	7	3	5	1	1	9	3	3	1	5
NH-19-3	3	5	5	5	3	1	1	9	3	3	1	7
NH-20-2	3	5	5	5	5	1	1	9	3	3	3	7
Pusa Arunima	3	5	7	5	9	1	1	1	1	1	1	7
Pusa Deepshikha	1	5	7	5	7	9	3	9	3	3	2	7
Pusa Lalima	1	5	7	5	7	1	1	9	3	1	1	3
Pusa Manohari	5	5	7	5	5	1	1	9	3	3	1	5
Pusa Peetamber	3	5	5	5	5	9	3	9	3	1	3	5
Pusa Pratibha	3	3	7	7	7	1	1	1	1	1	1	5
Pusa Shreshth	1	5	7	5	7	1	1	1	1	1	1	5

Inflorescence colouration : Anthocyanin coloration of rachis(1- absent or weak, 3- medium, strong- 5); Time of flowering 50% of the tree(3- early, 5- medium, 7- late); Fruit length (3- short (<5 cm), 5- medium (5-10 cm), 7- long (10-20 cm) and 9- extra long (>20 cm) ; Fruit width 3- (narrow (<5 cm), 5- medium (5-7 cm) and 7- broad (>7 cm); Mature fruit colour(1- only green, 3- green and yellow, 5- green and orange, 7- green and pink, 9- green and purple); Presence of cavity at stalk(1- absent, 9- absent); Depth of cavity at stalk (1- absent, 3- shallow); Fruit sinus type (1- absent, 9- present); Depth of Sinus (1- absent, 3- shallow); Fruit beak type (1- perceptible, 2- pointed, 3- prominent, 4- mammiform); Mature fruit shape (1- oblong, 2- elliptic, 3- roundish, 4- ovoid, 5- obovoid, 99- other); Maturity group: Fruits ready to harvest (3- early, 5- medium, 7- late

specific and consumer-oriented varieties. Horticultural traits, *viz*., red peel color, moderate sweetness, medium to large size fruits, dwarfness, salt tolerance, climate resilience, and resistance against emerging pests and diseases, are important in mango improvement. ICAR- Indian Agricultural Research Institute had stepped forward with the same objectives and released several new promising mango hybrids. Characterization of newly bred hybrids is of utmost importance for registration and protection of these mango hybrid varieties. DUS guidelines are one such approach to assist this and are widely utilized in many fruit crops (Krishna *et al.,* 2016; Wani *et al.,* 2017; Sridhar and Babu, 2017; Bhamini *et al.,* 2018; Dinesh *et al.,* 2018; Molla *et al.,* 2019; Jena *et al.,* 2021; Wang *et al.,* 2022 and Rasool *et al.,* 2022). DUS traits given in guidelines for the conduct of test for distinctiveness, uniformity and stability on mango are considered stable traits and less affected by environmental conditions. In the present study, mango hybrids showed significant variations for leaf length, width and area. It is indeed possible that cultivar differences arise due to the involvement of different heterozygous parents and thus can be attributed to variation in leaf size. Dinesh *et al.* (2018) also observed significant variability in leaf characters based on DUS guidelines among mango hybrids. Considering that

Table 3: Frequency distribution of quantitative and qualitative traits among 24 mango hybrids

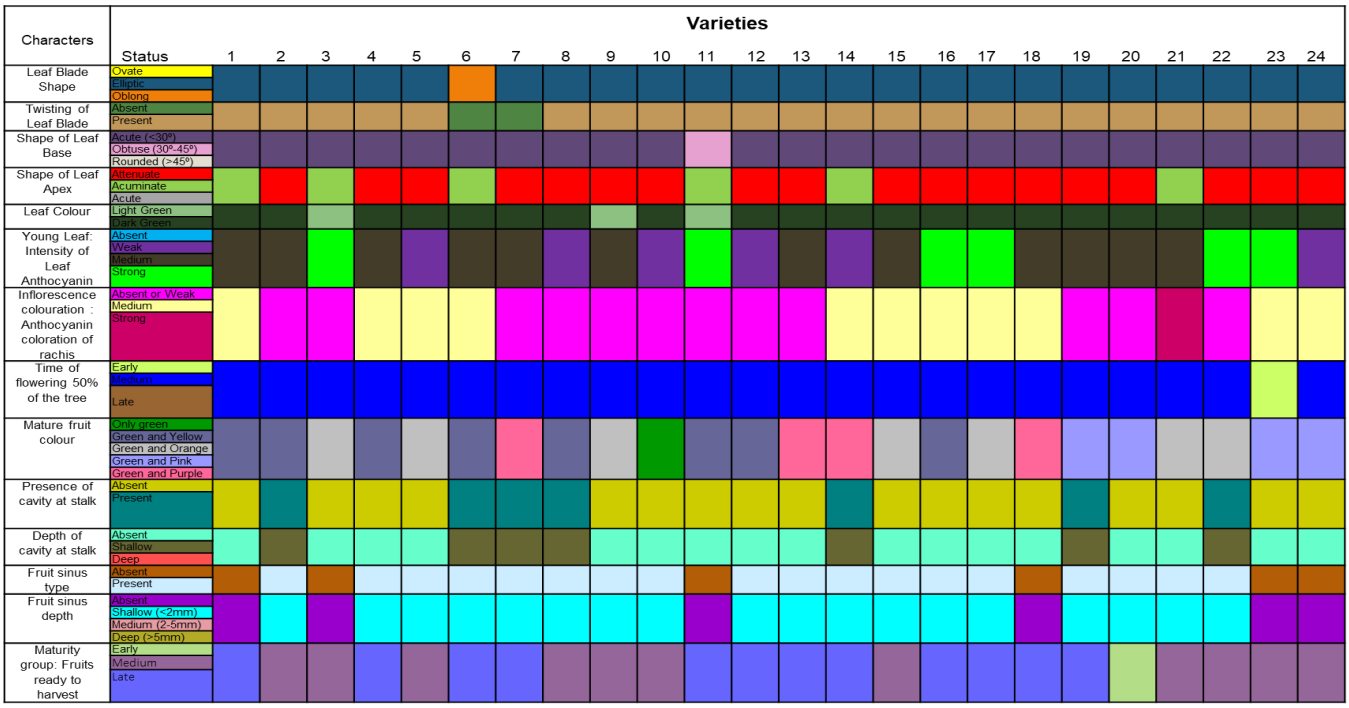
Trait	*Scale*	*F*	*RF(%)*	*DI*	*Trait*	*Scale*	*F*	*RF(%)*	*DI*
Leaf blade length	Long	3	12.50	0.37	Time of flowering: 50% of the tree	Early	1	4.16	0.17
	Medium	21	87.50			medium	23	95.83	
Leaf blade width	Medium	24	100	0	Fruit length	Medium	12	50	0.69
Petiole length	Long	9	37.50	0.66		Long	12	50	
	Medium	15	62.50		Fruit width	Broad	2	8.33	0.65
Leaf blade shape	Oblong	1	4.16	0.17		Narrow	3	12.50	
	Elliptic	23	95.83			Medium	19	79.16	
Twisting of leaf blade	Absent	2	8.33	0.28	Mature fruit colour	Only green	1	4.16	1.45
	Present	22	91.66			Green and purple	4	16.66	
Shape of leaf base	Obtuse	1	4.16	0.17		Green and pink	4	16.66	
	Acute	23	95.83			Green and orange	7	29.16	
Shape of leaf apex	Acuminate	6	25	0.56		Green and yellow	8	33.33	
	Attenuate	18	75		Presence of cavity at stalk	Present	7	29.16	0.60
	Acute	17	58.62			Absent	17	70.83	
Leaf colour	Light green	3	12.50	0.37	Depth of cavity at stalk	Shallow	7	29.16	0.60
	Dark green	21	87.50			Absent	17	70.83	
Intensity of leaf anthocyanin	Weak	6	25.00	1.06	Fruit sinus type	Absent	7	29.16	0.60
	Strong	7	29.16			Present	17	70.83	
	Medium	11	45.83		Depth of sinus	Absent	7	29.16	0.60
Inflorescence length	Short	2	8.33	0.92		Shallow	17	70.83	
	Medium	11	45.83		Fruit beak type	Pointed	3	12.5	0.97
	Long	11	45.83			Prominent	9	37.5	
Inflorescence width	Medium	8	33.33	0.63		Perceptible	12	50	
	Long	16	66.66		Mature fruit shape	Roundish	2	8.33	0.98
Anthocyanin coloration of rachis	Strong	1	4.13	0.83		Elliptic Obovoid	2 4	8.33 16.66	
	Medium	11	45.83			Oblong	16	66.66	
	Absent or weak	12	50.00						
					Maturity groups: Fruit ready to harvest	Early Medium Late	1 11 12	4.16 45.83 50.00	0.83

F- Frequency, RF- Relative frequency and DI – Diversity index

plants with greater leaf areas offer higher photosynthetic rates and may be affecting the fruit size and quality. The present findings corroborated with the findings of Rhodes *et al.* (1970); Rajwana *et al.* (2011); Joshi *et al.* (2013); Wani *et al.* (2017) and Balamohan and Vidhya (2020).

Leaf qualitative traits among mango hybrids also differed significantly and in conformity to the similar findings by Jena *et al.* (2021) who reported oblong leaf shape in most of the genotypes and ranging from rounded to acuminate. In the present studies, the acuminate type of leaf apex was

Table 4: DUS fingerprints of mango hybrids based on horticultural traits



1- Amrapali, 2- H-1-11, 3- H-12-5, 4- H-1-5, 5- H-2-14 , 6- H-3-2 , 7- H-4-8, 8- H-7-1, 9- Mallika, 10- NH-16-2, 11- NH-17-1, 12- NH-17-3, 13- NH-17-4. 14- NH-18-4, 15- NH-19-2, 16- NH-19-3, 17- NH-20-2, 18- Pusa Arunima, 19- Pusa Deepshikha, 20- Pusa Lalima, 21- Pusa Manohari, 22- Pusa Peetamber, 23- Pusa Pratibha, 24- Pusa Shreshth

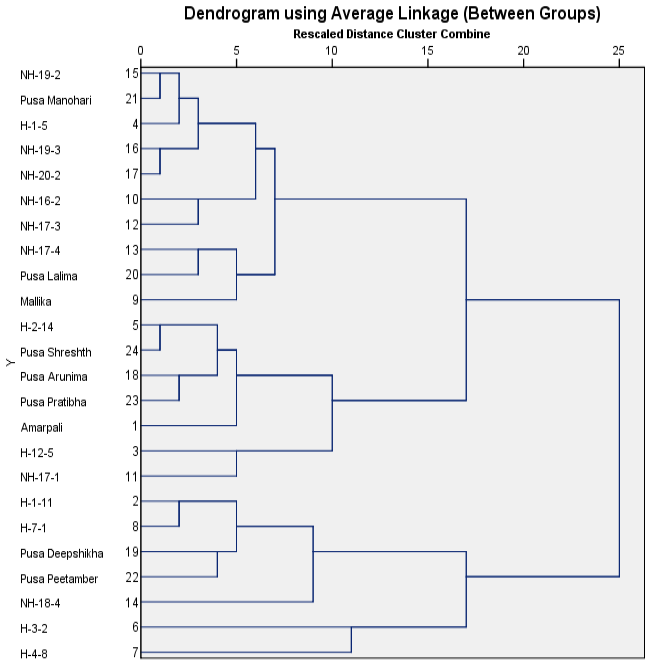


Figure 1: Dendrogram depicting average linkage between mango hybrids

recorded in hybrids, namely, Amrapali, H-12-5, H-3-2, NH-17-1, NH-18-4 and Pusa Manohari. Likewise, mature leaf color results were in accordance with the findings of Fivaz (2008). Results pertaining to intensity of anthocyanin coloration in young leaves clearly indicated significant variation in three distinct classes: weak, medium and strong. Earlier, Molla *et al.* (2019) also reported such findings in mango genotypes of Bangladesh. Mango leaves can change color as they mature, transitioning from copper brown to light greenish and dark green as reported by Mezel *et al.* (2017). As the juvenile leaves grows they tend to accumulate more chlorophyll and their net carbon absorption rises initially from net carbon importers to net CO_2 assimilation.

Every mango genotype has a distinct flowering period thus it may be often tied to the prevailing environmental conditions, genetics, nutrition levels, and hormonal elements (Kulkarni, 2004). Present findings are in agreement with these reports and showed that mango hybrids had different flowering times. Pusa Pratibha was recorded with the earliest flowering amongst all hybrids during the period of study. Inflorescence length and width are key factors influencing the pollinator activity and fruit set by offering a larger surface area. We observed the maximum inflorescence length (46.58 cm) in H-7-1. Pandit *et al.* (2017) also reported similar kind of findings based on DUS characterization.

Twelve hybrids (50%) had fruit lengths more than 10 cm. Ranjith *et al.* (1982) also hypothesized that environmental influences may have a greater impact on fruit size than genetics alone. The fruit size is highly dependent on initial cell division and further enlargement of these cells. Prevailing environmental condition significantly influence division and enlargement of cell. Using its resources effectively, a cultivar may have the innate potential to yield fruits of greater size. Kumar *et al.* (2016) also reported similar

results pertaining in apples under the northern Himalayas. It has been suggested that mango fruit shape has a significant role in packaging and transportation. Our results showed considerable variation in fruit shape index. Amongst mango hybrids, NH-17-1 had the maximum (2.33) fruit shape index at par with NH-19-2 (2.29) and NH-17-1 (1.93), suggesting their elliptical or oblong fruit shape. The data regarding fruit weight of different mango hybrids suggested a wide range of variations ranging from 94.87 to 336.44 g. Medium-sized mango fruits between 200 to 250 g are preferred for marketing. Mallika had the maximum (336.44 g) fruit weight while the minimum (94.87 g) was in NH-19-2. Similar variations have also been noticed in mango by Wani *et al.* (2017); Molla *et al.* (2019) and Mango Genome Consortium *et al.* (2021). Our findings strongly agree with the findings of Rymbai *et al*. (2014), who speculated that transgressive segregation or additive gene action might impact the quantitative characteristic in mango hybrids. One of the key fruit quality attributes that determine the attractiveness and marketability of the fruits is their aesthetic and visual appeal. Fruit peel color was an incredibly variable trait spread over 5 phenotypic classes. Thus, a useful color library for identifying distinct mangoes may be created. Singh *et al.* (2012) also reported a wide range of peel coloration amongst mango hybrids and further suggested their utilization in developing red peel color hybrids which fetch more price in international markets. In the present study, a positive correlation was observed between the presence of cavities and depth at the stalk. It was noted that amongst 24 hybrids, a shallow cavity was present in 70.83%. A similar kind of correlation exists between fruit sinus and depth of sinus. Additionally, mangoes are categorized in the global market according to customer preferences for shape and peel color (Campbell, 1995). The maximum (66.66%) hybrids in the present investigation had an oblong fruit shape. Shamili *et al.* (2012) evaluated fruit morphologies and found that Iranian genotypes exclusively produced elongated and oblong fruit shapes. It was interesting to note that all the hybrids can be broadly grouped into 3 groups for fruit maturity. Pusa Lalima has been documented with early fruit maturity. Additionally, it has been discovered that elevated and fluctuating temperatures during the early stages of fruit growth have an impact on fruit maturity (Kumar *et al.,* 2016).

Significant variations between mango hybrids were observed in terms of both qualitative and quantitative traits. Out of 23 traits, 5 were significant ($p \leq 0.001$) across the two clusters. Earlier, Harisha *et al.* (2021) developed a similar kind of DUS fingerprint while studying diversity analysis in rice genotypes and reported its efficiency in the identification of informative traits. In the present investigation, morphological parameters suggested in DUS guidelines have been used for generation of fingerprints for mango hybrids. This fingerprint is highly useful in the future identification, protection and conservation of mango.

Conclusion

Twenty-four mango hybrids have been characterized based on DUS guidelines and hybrid-specific stable morphological traits have been identified. The unique traits have immense value in identifying, protecting and conserving these hybrids. Furthermore, the genetic relatedness based on the diversity analysis provided useful information for the utilization of these hybrids in future breeding programmes as the source of important desirable traits. Attractive fruit peel color, early fruit maturity, and fruit weight are traits of economic importance that must be utilized for mango improvement in future breeding programs. DNA fingerprints based on DUS guidelines will further help to identify and protect these hybrids.

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References

APEDA (2020-21). Agricultural and Processed Food Products Export Development Authority. *India Exports Statistics*. New Delhi, India. *https://agriexchange.apeda.gov.in/*

Balamohan, T. N., & Vidhya, D. (2020). Evaluation of traditional mango (Mangifera indica L.) varieties of Tamil Nadu for fruit quality attributes. *Int. j. chem. biochem. sci.*, **18**: 57-62.

Bhamini, K., Jaiswal, U. S., Ahmad, M. F., & Nayyer, A. (2018). Studies on the physio-morphology, flowering and fruit characteristics of mango genotypes in subtropical climate of Eastern India. *J. pharmacogn. phytochem.*, **7(2)**: 3783-3789.

Burns, W., & Prayag, S. H. (1921). The book of the mango. Department of Agriculture, Bombay. *Bull*, *103*.

Campbell, C. D. B., & Bernard, R. (1995). Mangos in the United States: A year long supply. In *Florida State Horticultural Society. Meeting (USA)*, **107***:* 303-334.

Menzel, C. M., & Le Lagadec, M. D. (2017). Can the productivity of mango orchards be increased by using high-density plantings? *Sci. Hortic.*, **219**: 222-263.

Dinesh, M. R., Ravishankar, K. V., Gowda, D. S., & Sankaran, M. (2018). Morphological characterization and genetic barcoding of kuttiatoor mango accessions.

Fivaz, J. (2008). Botanical aspects. In: de Villiers EA, Joubert PH (Eds.) The Cultivation of Mango. ARC Institute for Tropical and Subtropical Crops, Florida, USA, pp 9-20.

Harisha, R., Bhadru, D., Vanisri, S., Gourishanakar, V., & Satish, L. (2021). SSR and morphological traits based fingerprints and DNA barcodes for varietal identification in rice. *Biotechnol. Biotechnol. Equip.*, **35(1)**: 1461-1473.

Jena, R. C., Agarwal, K., & Chand, P. K. (2021). Fruit and leaf diversity of selected Indian mangoes (*Mangifera indica* L.). *Sci. Hortic.*, **282**: 109941.

Joshi, R., Kundu, M., & Singh, C. P. (2013). Morphological characters: efficient tool for identification on different mango cultivars.

Environ. Ecol., **31(1A)**: 385-388.

Krishna, H., Bhargava, R., Chauhan, N., & Sharma, S. K. (2016, June). Morphological descriptor for DUS testing of Indian jujube (*Ziziphus mauritiana*). *Indian J. Agric. Sci.,* **86(6)**: 809-814.

Kulkarni, V. J. (2004). The tri-factor hypothesis of flowering in mango. In *VII International Mango Symposium 645* (pp. 61-70).

Kumar, J., Thakur, D., & Thakur, M. (2016). Long Term Performance of Some Spurs and Colour Strains of Apple (*Malus domestica* Borkh.) under Low Altitude Conditions of Kullu Valley of Himachal Pradesh. *Int. j. bio-resour. stress manag.*, **7(1)** 40-46.

Mango Genome Consortium, Bally, I. S., Bombarely, A., Chambers, A. H., Cohen, Y., Dillon, N. L., ... & Yan, H. (2021). The 'Tommy Atkins' mango genome reveals candidate genes for fruit quality. *BMC Plant Biology*, **21**: 1-18.

Molla, M. R., Ahmed, I., Hossain, M. A., Islam, M. S., Chowdhury, M. A. Z., Shabnam, D., & Rohman, M. M. (2019). Morphological characterization and Simple Sequence Repeats (SSRs) based DNA fingerprinting of selected mango (*Mangifera indica* L.) genotypes in Bangladesh. *j. hortic. for.*, **11(7)**: 104-119.

Mukherjee, S. K. (1951). The origin of mango. *Indian J Genet Plant Breed., 2*, 49.

NHB (2019-20). *Indian Horticulture Database*. Gurugram, India. *http://www.nhb.com*

Pandit, B. A., Wani, M. S., Dar, S. A., & Rashid, R. (2017). Blooming behavior of exotic apple cultivars under North Himalayan Region of India. *Int J Curr Microbiol Appl Sci, Int J Curr.*, **6(2)**: 1765-1775.

PPV & FRA (2020). Guidelines for conduct of test for DUS Mango (*Mangifera indica* L.), Protection of Plant Varieties and Farmers Right Authority, GOI, NASC Complex, DPS Marg, New Delhi, 17 P

Rajwana, I. A., Khan, I. A., Malik, A. U., Saleem, B. A., Khan, A. S., Ziaf, K., ... & Amin, M. (2011). Morphological and biochemical markers for varietal characterization and quality assessment of potential indigenous mango (*Mangifera indica*) germplasm. *International Journal of Agriculture and Biology*, **13**: 151-158.

Ranjith, P. J. (1982). Evaluation of mango *(Mangifera indica* L.) hybrids for certain useful characters. M.Sc. thesis submitted to the PG School IARI, New Delhi, 69 p.

Rasool, A., Bhat, K. M., Mir, M. A., Jan, A., Dar, N. A., & Mansoor, S. (2022). Elucidating genetic variability pertaining to flowering, maturity and morphological characters among various apple (*Malus domestica* Borkh.) cultivars. *S. Afr. J. Bot.*, **145**: 386-396.

Rhodes, A. M., Campbell, C., Malo, S. E., & Carmer, S. G. (1970). A Numerical Taxonomic Study of the Mango (*Mangifera indica* L.). *J. Am. Soc. Hortic. Sci.*, **95(2)**: 252-256.

Rymbai, H., Laxman, R. H., Dinesh, M. R., Sunoj, V. J., Ravishankar, K. V., & Jha, A. K. (2014). Diversity in leaf morphology and physiological characteristics among mango (*Mangifera indica* L.*)* cultivars popular in different agro-climatic regions of India. *Sci. Hortic.*, **176**: 189-193.

Shamili, M., Fatahi, R., & Hormaza, J. I. (2012). Characterization and evaluation of genetic diversity of Iranian mango (*Mangifera indica* L., Anacardiaceae) genotypes using microsatellites. *Sci. Hortic.*, **148**: 230-234.

Singh, A., Singh, A. K., & Singh, S. K. (2012). SSR markers reveal genetic diversity in closely related mango hybrids. *Indian J Hortic*, **69(3)**: 299-305.

Singh, R. N., Majumder, P. K., Sharma, D. K., & Mukherjee, S. K. (1972). Some promising mango hybrids. *Acta Hortic.,* **24**: 117-119.

Sridhar, R., & Harish Babu, B. N. (2017, September). A novel pomegranate (*Punica granatum* L.) variant with high anthocyanin content. In *International Symposium on Horticulture: Priorities and Emerging Trends,* **1255**: 149-152.

Wang, Y., Hu, G. P., Liu, Z. S., Zhang, J., Ma, L., Tian, T., ... & Wang, X. R. (2022). Phenotyping in flower and main fruit traits of Chinese cherry [*Cerasus pseudocerasus* (Lindl.) G. Don]. *Sci. Hortic.*, **296**: 110920.

Wani, A. A., Zargar, S. A., Malik, A. H., Kashtwari, M., Nazir, M., Khuroo, A. A., ... & Dar, T. A. (2017). Assessment of variability in morphological characters of apricot germplasm of Kashmir, India. *Sci. Hortic.*, **225**: 630-637.