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Effect of different rootstocks for plant growth and fruit quality attributes in mango (*Mangifera indica*) cultivars

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ABSTRACT

Identification of suitable rootstock and scion combination is fundamental in grafting to acquire beneficial traits and higher productivity. The present investigation was carried out to study the effect of the polyembryonic mango (*Mangifera indica* L.) rootstocks (Pusa Aam Moolvrant-2, Kurukkan and Olour) on scion cultivars (Dashehari and Mallika), based on the physico-chemical fruit quality traits along with growth and yield attributes. It was conducted during 2022 and 2023 at ICAR-Indian Agricultural Research Institute, New Delhi. Results revealed that the highest total soluble solids (23.23ºB), titratable acidity (0.30%) and ascorbic acid (37.00 mg/100 g) were found in the Mallika/Olour combination. Dashehari and Mallika both had the highest TSS, titratable acidity and ascorbic acid with Olour rootstock. Canopy volume (381.13 m^3), trunk cross-sectional area (1,326.08 cm^2) and yield/tree (56.85 kg/tree) were found to be highest in Mallika/Pusa Aam Moolvrant-2 and lowest in Dashehari/Kurukkan (111.68 m^3, 619.89 cm^2 and 19.91 kg/tree, respectively). The principal component analysis for physico-chemical, growth and yield traits showed major traits contributing to the rootstock/scion influence along the first three components, explaining 92.41% of the total variation among the studied scion/rootstock combinations in mango. The study showed that apart from the well-known effect of rootstock on plant growth, fruit quality traits are also effected by rootstock; and specific scion-stock combinations may be exploited for desirable traits. The findings indicated that rootstock 'Olour' is promising for mango cultivars for improved fruit quality and nutritional value while 'Pusa Aam Moolvrant-2' is superior for desirable growth and yield traits.

Keywords: Antioxidants, Planting density, Scion, Stionic influence

Mango (*Mangifera indica* L.), considered the 'King of fruits,' is part of India's cultural and religious symbols. Major constraint in mango cultivation is the low planting density in traditional orchard planning. A suitable dwarfing rootstock is one of the most essential pre-requisites in this direction to harness the potential of a wide range of improved cultivars. Being a perennial fruit crop with high heterozygosity, propagation through seed is not recommended in mango. Therefore, it is propagated through asexual methods like grafting. In mango, the effect of rootstocks on scion growth (Dayal *et al.* 2016, Kajtar-Czinege *et al.* 2022), fruit quality (Valverdi and Kalcsits 2021) and abiotic stress have been reported previously, however, the influence on fruit quality and nutritional properties is poorly understood. In arable crops, phenotypic variability usually reveals the genotype × environment interaction (G×E), however, in grafted plants, the phenotype is more complex since it joins two different genotypes, producing R × S × E interactions that are pushed by the connection between the rootstock (R) and the scion (S).

Rootstock and scion are usually genetically diverse from each other, which can result in an interactive and multifactorial effect on fruit quality (Shivran *et al.* 2023). 'Kurukkan' and 'Olour' are the polyembryonic rootstocks in India which had been explored for rootstock traits and recently, a potential polyembryonic rootstock, i.e. 'Pusa Aam Moolvrant-2' has been identified at ICAR-Indian Agricultural Research Institute (IARI), New Delhi. Dashehari is a traditional cultivar growing extensively in the northern Indian states and Mallika is a promising regular-bearing hybrid (Neelum × Dashehari) developed from systematic breeding efforts at ICAR-IARI, New Delhi. Identifying suitable rootstock with desirable rootstock/scion combinations for these cultivars is required to maximise productivity and sustainable mango farming. Keeping in view, the present research was carried out to investigate the effect of three polyembryonic rootstocks (Pusa Aam Moolvrant-2, Kurukkan and Olour) on plant growth, yield

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and fruit quality traits of 'Dashehari' and 'Mallika' cultivars.

MATERIALS AND METHODS

The present experiment was carried out during 2022 and 2023 (pooled study of both year) at Research Farm, ICAR-Indian Agricultural Research Institute (28.08°N, 77.12°E; at an elevation of 228.61 m amsl), New Delhi on 16 years old trees of two high-yielding varieties (Dashehari and Mallika), grafted on three polyembryonic rootstocks (Pusa Aam Moolvrant-2, Kurukkan and Olour). Experimental trees were planted at 4 m × 4 m apart with six trees in each stionic combination. These experimental plants were subjected to parameters, yield potential and physico-chemical fruit quality parameters. Fruits of the selected scion rootstock combinations were harvested at maturity and observations were taken from the ripe fruits. Immediately after harvesting, fruits were brought to the laboratory and subjected to washing and desapping. Standard procedures were followed for TSS, titratable acidity (TA) and ascorbic acid determination of fruit pulp (Ranganna 1999).

Antioxidant activity, total phenols and total flavonoids were determined from the pulp tissue of ripe fruits (Sharma *et al.* 2016). The total phenolic content of the samples was estimated using the Folin-Ciocalteu method. An aliquot of 100 µL of extract was mixed with deionised water, Folin-Ciocalteu reagent and 20% Na_2CO_3, and after 30 min, the absorbance was recorded at 760 nm. The results were expressed as mg gallic acid equivalents (GAE)/100 g fresh weight (FW). The total flavonoid content was determined as mg quercetin equivalents (QE)/100 g. The extract was reacted sequentially with $NaNO_2$, $AlCl_3$ and NaOH and the final volume was adjusted to 10 mL before measuring absorbance at 510 nm. Antioxidant activity was analysed using the CUPRAC assay and the values were expressed as µmol Trolox/g FW.

The canopy volume (CV) (Castle 1983) and trunk cross-sectional area (TCSA) were calculated as

$$CV = 4/3 \times \pi \times a^2b$$
$$TCSA = \pi\ (d/2)^2$$

Where d, Trunk diameter; a, Average plant spread; b, half of the tree height.

At the time of fruit maturity, the number of fruits was counted per tree and yield/plant was obtained for individual plants and expressed as kg/plant. Yield efficiency (YE) was determined as yield in kg/trunk cross sectional area in cm^2 (Westwood *et al.* 1963). The fruiting density was calculated as the number of fruits/unit canopy volume (Smith *et al.* 2004). Two plants of each combination (scion-rootstock) were considered as single replication and all the estimates were triplicated. The obtained data were subjected to one-way Analysis of Variance (ANOVA), with statistical significance determined at $p \leq 0.05$. Pearson's correlation analysis was conducted to examine the association among the estimated parameters. Principal component analysis (PCA) was performed for the mean value of studied traits to differentiate among the scion-rootstock combinations and identifying major traits underlying variations. These analyses were carried out using R Studio (Version 2022.07.1–554).

RESULTS AND DISCUSSION

Plant growth, yield and fruit quality traits: In the present study, the interaction among the rootstock and scion significantly affected the vigour of the grafted plant as the results of growth analysis (plant height, tree spread, canopy volume and TCSA) indicated among the investigated rootstock × scion interactions. Results pertaining to physico-chemical and growth yield traits indicated the existence of significant variability among the scion/rootstock combinations (Table 1). Fruit weight, pulp recovery and pulp/stone ratio were significantly affected by scion, rootstocks and interaction between scion and rootstock. Among the varieties, Mallika had large fruit (269.45 g) and pulp weight (197.50 g) compared to Dashehari. Both the cultivars had higher fruit and pulp weight with Pusa Aam Moolvrant-2, while Kurukkan and Olour rootstock led to reduced fruit size and pulp content in Mallika and Dashehari. Stone weight was not consistent with rootstocks, indicating the varietal influence and interaction of scion genotype with rootstock. The pulp/stone ratio indicated a proportion of edible matter in the mango fruit and a higher ratio is desirable. The Pusa Aam Moolvrant-2 led to the higher pulp/stone ratio in both the cultivars compared to the other two rootstocks as the Dashehari exhibited the maximum pulp/stone ratio (5.28) with Pusa Aam Moolvrant-2 and minimum (3.73) with Kurukkan rootstock (i.e. 70% reduction). Mallika/Pusa Aam Moolvrant-2 combination exhibited the heaviest fruit weight, pulp content and pulp/stone ratio while lowest was recorded in Dashehari/Kurukkan.

Previous studies have demonstrated that rootstock genotypes can significantly alter the fruit size and pulp content of grafted scion varieties in crops such as pear (Askari-Khorasgani *et al.* 2019), mango (Shivran *et al.* 2023) and lemon (Ziogas *et al.* 2023). The rootstock in the grafted plant is responsible for the absorption of nutrients and water from the soil apart from influencing the sink source. Therefore, the difference in the fruit size and pulp content with rootstock indicated the inherent potential of rootstock by contributing to the optimum water nutrient and photoassimilate balance during the fruit growth period. The results of this study highlight the significant influence of rootstock and scion cultivar on the growth parameters of mango trees, consistent with previous research studies, where rootstock-scion interactions have been shown to affect tree vigour, canopy size and graft compatibility in pear (Ikinci *et al.* 2014) and mango (Dubey *et al.* 2021). Recent study by Somkuwar *et al.* (2023) further emphasises that rootstocks can modulate hormonal signalling pathways especially auxin and cytokinin balance which leads to altered assimilate partitioning, influencing fruit size parameters in grafted perennial fruit crops. Moreover, transcriptomic studies have shown that specific rootstocks can upregulate genes related to sugar transporters and cell expansion in developing fruits (Shivran *et al.* 2023), which may partly explain the

Table 1 Evaluation of physical fruit quality traits of mango across different polyembryonic rootstocks

Scion/rootstock combinations	Fruit quality traits					
	Fruit weight (g)			Pulp weight (g)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	180.83^{b}	269.45^{a}	225.14^{A}	118.66^{cd}	197.50^{a}	158.08^{A}
Kurukkan	125.49^{c}	243.68^{a}	184.59^{B}	83.33^{e}	170.36^{b}	126.84^{B}
Olour	134.82^{c}	208.57^{b}	171.70^{B}	93.16^{de}	142.66^{c}	117.91^{B}
Mean	147.05^{B}	240.57^{A}		98.38^{B}	170.17^{A}	
LSD (p≤0.05)	C	R	C × R	C	R	C × R
	16.45	20.15	28.49	15.44	18.91	26.74
Scion/rootstock combinations	Pulp/stone ratio			Stone weight (g)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	5.28^{cd}	8.74^{a}	7.01^{A}	22.56^{b}	31.32^{a}	26.94^{A}
Kurukkan	3.73^{d}	7.64a^{b}	5.68^{B}	22.33^{b}	32.15^{a}	27.24^{A}
Olour	4.55^{d}	6.89b^{c}	5.72^{B}	21.16^{b}	33.71^{a}	27.44^{A}
Mean	4.52^{B}	7.76^{A}		22.02^{B}	32.39^{A}	
LSD (p≤0.05)	C	R	C × R	C	R	C × R
	1.02	1.25	1.77	NS	NS	NS

C, Cultivar; R, Rootstock; NS, Non-significant. The capital letter indicates the significance between the mean values for respective trait at cultivar and rootstock level individually. Whereas, the small letters indicate the significance at the cultivar × rootstock interaction level.

superior pulp development observed in combinations such as Mallika/Pusa Aam Moolvrant-2. These results indicated the complex rootstock scion interaction and underpin the importance of carefully selecting rootstock for specific scion for optimising fruit quality and commercial yield. Given the increasing focus on climate-resilient horticulture, choosing rootstocks that enhance both productivity and adaptability is becoming a critical strategy for sustainable mango cultivation (Somkuwar *et al.* 2023).

The biochemical traits were also significantly affected (Table 2). Considering the scion cultivars, Mallika displayed a higher TSS, ascorbic acid, total phenol, total flavonoids and total antioxidant activity, while Dashehari fruit pulp had a higher TA. It has been observed that the scion cultivar grafted on Olour rootstock exhibited higher TSS, TA and ascorbic acid content, followed by Pusa Aam Moolvrant-2 and lowest in Kurukkan. The highest TSS (23.23ºB), titratable acidity (0.30%) and ascorbic acid (37.00 mg/100 g) were found in the Mallika/Olour combination. However, the TSS/acid ratio was statistically similar for all three rootstocks. In our study, both vigorous rootstocks (Olour and Kurukkan) were noted to increase the TSS content, irrespective of the scion, compared to the dwarfing rootstock (Pusa Aam Moolvrant-2). In contrast, Paolo Mauro *et al.* (2020) found that grafting onto the most vigorous rootstocks reduced TSS.

The mango fruits are known for their health-promoting properties and are also known as protective food due to the abundance of vitamins, minerals and antioxidants. In the present study, total phenol, total flavonoids and total antioxidant activity were found to vary with the scion/rootstocks combination (Table 2), although the results were inconsistent with the rootstocks. It indicated that rootstock influences the different cultivars differently, resulting from a complex interaction of scion genotypes, environment and R × S interaction. The pulp of Mallika was rich in ascorbic acid content and total phenol content, which shows its superiority over its parental genotype, Dashehari; however, in both the cultivars, total flavonoids and total antioxidant capacity were found to be statistically similar. Among the rootstock/scion combinations, the total phenol and total antioxidant activity were recorded maximum in the Mallika/Olour combination (106.30 mg GAE/100 g and 4.88 µmol TE/g). The minimum total flavonoids were recorded in both cultivars (Dashehari and Mallika) on Olour rootstock 11.16 and 11.63 mg QE/100g, respectively. These results are in agreement with the findings of Milosevic *et al.* (2018), who also reported that the scion/rootstock combinations influenced total phenol, total flavonoids and total antioxidant activity in apple. The improvement in TSS and antioxidants in Mallika grafted on Olour might be due to enhanced carbohydrate translocation efficiency and enhanced mineral uptake in vigorous rootstocks. Previous studies have highlighted that rootstocks with higher vigour often enhance photosynthate allocation to fruits, thereby improving sugar accumulation and secondary metabolite profiles (Shivran *et al.* 2023). Similarly, the elevated phenolic and flavonoid content in Mallika/Olour combinations aligned with reports suggesting that rootstock-induced modulation of phenylpropanoid pathway enzymes can

Table 2 Evaluation of biochemical fruit quality traits and antioxidants in mango across different polyembryonic rootstocks

Scion/rootstock combinations	Biochemical traits					
	TSS (ºB)			Titratable acidity (%)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	19.96^{c}	22.00^{b}	20.98^{B}	0.29^{a}	0.25^{b}	0.27^{B}
Kurukkan	20.33^{c}	21.90^{b}	21.11^{B}	0.25^{b}	0.27^{ab}	0.26^{B}
Olour	20.93^{bc}	23.23^{a}	22.08^{A}	0.29^{a}	0.30^{a}	0.29^{A}
Mean	20.41^{B}	22.37^{A}		0.27^{A}	0.27^{A}	
LSD (p≤0.05)	C	R	C × R	C	R	C × R
	0.70	0.86	1.22	0.018	0.022	0.032
Scion/rootstock combinations	TSS/acid ratio			Ascorbic acid (mg/100 g)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	68.48^{c}	88.05^{a}	78.26^{A}	28.33^{c}	32.61^{b}	30.47^{B}
Kurukkan	80.77^{ab}	79.43^{ab}	80.10^{A}	28.35^{c}	33.07^{b}	30.71^{B}
Olour	74.31^{bc}	75.91^{bc}	75.11^{A}	29.58^{bc}	37.00^{a}	33.29^{A}
Mean	74.52^{B}	81.13^{A}		28.75^{B}	34.23^{A}	
LSD (p≤0.05)	C	R	C× R	C	R	C × R
	6.16	7.54	10.67	2.027	2.483	3.511
Scion/rootstock combinations	Total phenol (mg GAE/100 g)			Total flavonoids (mg QE/100 g)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	80.50^{bc}	95.48^{ab}	87.99^{A}	13.66^{ab}	14.79^{a}	14.23^{A}
Kurukkan	73.00^{c}	96.83^{a}	84.91^{A}	13.20^{abc}	13.23^{abc}	13.21^{A}
Olour	76.33^{c}	106.30^{a}	91.31^{A}	11.16^{c}	11.63^{bc}	11.40^{B}
Mean	76.61^{B}	99.53^{A}		12.67^{A}	13.21^{A}	
LSD (p≤0.05)	C	R	C × R	C	R	C× R
	8.78	10.75	15.21	1.31	1.60	2.27

Total antioxidant (CUPRAC) (µmol TE/g)			
Scion/rootstock combinations	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	4.37^{abc}	4.49^{ab}	4.43^{A}
Kurukkan	3.88^{bc}	3.72^{c}	3.80^{A}
Olour	4.29^{abc}	4.88^{a}	4.58^{A}
Mean	4.18^{A}	4.36^{A}	
LSD (p≤0.05)	C	R	C × R
	0.44	0.53	0.76

*C, Cultivar; R, Rootstock; TSS, Total soluble solids. The capital letter indicates the significance between the mean values for respective trait at cultivar and rootstock level individually. Whereas, the small letters indicate the significance at the cultivar × rootstock interaction level.

significantly alter antioxidant potential in mango and other fruit crops (Shivran *et al.* 2023, Somkuwar *et al.* 2023). The contrasting behaviour observed with Kurukkan, i.e. increasing TSS but decreasing ascorbic acid and phenolics, indicated that rootstock effects are trait-specific and may involve differential hormonal signalling that influences fruit biochemical pathways. Such genotype-rootstock specific interactions have recently been emphasised as key determinants of fruit nutritional quality in grafted fruit plants (Valverdi and Kalcsits 2021, Somkuwar *et al.* 2023).

Rootstock selection significantly (p≤ 0.05) influenced tree height, TCSA, canopy volume, yield, yield efficiency and fruiting density (Table 3). Mallika/Pusa Aam Moolvrant-2 combination exhibited the highest plant spread (6.23 m) and tree height (4.66 m) and the lowest plant spread was recorded in the Dashehari cultivar on Pusa

Table 3 Evaluation of growth and yield of mango across different polyembryonic rootstocks

Scion/rootstock combinations	Growth and yield attributes					
	Average spread (m)			Height (m)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	3.82^{d}	6.23^{a}	5.03^{A}	4.00^{b}	4.66^{a}	4.33^{A}
Kurukkan	3.97^{d}	6.13^{a}	5.05^{A}	3.36^{c}	4.63^{a}	4.00^{B}
Olour	4.68^{c}	5.22^{b}	4.95^{A}	3.83^{b}	4.15^{b}	3.99^{B}
Mean	4.16^{A}	5.86^{A}		3.73^{A}	4.48^{A}	
LSD (p≤0.05)	C	R	C × R	C	R	C × R
	0.21	0.26	0.37	0.21	0.25	0.36
Scion/rootstock combinations	Canopy volume (m^3)			TCSA (cm^2)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	123.13^{d}	381.13^{a}	252.13^{A}	772.18^{c}	1326.08^{a}	1049.13^{A}
Kurukkan	111.68^{d}	365.82^{a}	238.75^{AB}	619.89^{c}	1312.31^{a}	966.10^{B}
Olour	176.31^{c}	238.58^{b}	207.45^{B}	882.07^{bc}	1171.19^{ab}	1026.63^{A}
Mean	137.04^{B}	328.51^{A}		758.05^{B}	1269.86^{A}	
LSD (p≤0.05)	C	R	C × R	C	R	C × R
	29.02	35.55	50.27	186.79	228.77	323.53
Scion/rootstock combinations	Yield (kg/tree)			Yield efficiency (kg/m^3)		
	Dashehari	Mallika	Mean	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	32.69^{c}	56.85^{a}	44.77^{a}	1.484^{a}	0.706^{c}	1.095^{A}
Kurukkan	19.91^{d}	47.56^{b}	33.74^{b}	1.133^{b}	0.670^{c}	0.901^{B}
Olour	29.83^{c}	44.66^{b}	37.24^{b}	0.771^{c}	0.886^{bc}	0.829^{B}
Mean	27.48^{b}	49.69^{a}		1.129^{A}	0.754^{B}	
LSD (p≤0.05)	C	R	C × R	C	R	C × R
	4.87	5.96	8.43	0.148	0.182	0.257

	Fruiting density (m^3 CV)		
Scion/rootstock combinations	Dashehari	Mallika	Mean
Pusa Aam Moolvrant-2	1.478^{a}	0.556^{c}	1.017^{A}
Kurukkan	1.419^{a}	0.532^{c}	0.976^{A}
Olour	1.257^{a}	0.915^{b}	1.086^{B}
Mean	1.385^{A}	0.668^{B}	
LSD (p≤0.05)	C	R	C × R
	NS	0.200	0.283

C, Cultivar; R, Rootstock; NS, Non-significant; TCSA, Trunk cross-sectional area; CV, Canopy volume. The capital letter indicates the significance between the mean values for respective trait at cultivar and rootstock level individually. Whereas, the small letters indicate the significance at the cultivar × rootstock interaction level.

Aam Moolvrant-2 (3.82 m) rootstock and the least plant height was observed for Dashehari on Kurukkan (3.36 m) rootstock. The mean effect of rootstock exhibited the highest spread with Kurukkan (5.05 m) followed by Pusa Aam Moolvrant-2 (5.03 m) and the lowest in Olour (4.95 m). Canopy volume (381.13 m^3), TCSA (1326.08 cm^2) and yield/tree (56.85 kg/tree) were found to be highest in Mallika/Pusa Aam Moolvrant-2 and lowest in Dashehari/Kurukkan (111.68 m^3, 619.89 cm^2 and 19.91 kg/tree, respectively). The mean effect of rootstock exhibiting maximum canopy volume was recorded in Pusa Aam Moolvrant-2 (252.13 m^3) followed by Kurukkan (238.75 m^3) and all rootstocks were found statistically significant. Yield efficiency (0.886 kg/m^3) and fruiting density (0.915 m^3 CV) were maximum in Mallika/Olour combination. The mean effect of rootstock with highest fruiting density was observed in Olour (1.086

m^3 CV) followed by Pusa Aam Moolvrant-2 (1.017 m^3 CV) and lowest in Kurukkan (0.976 m^3 CV), but Pusa Aam Moolvrant-2 and Kurukkan were found statistically similar. Previously, similar results were also observed in citrus, grapes, apples and pears (Kumar *et al.* 2019). Mallika cultivar has vigorous growth, with all the evaluated rootstock having the highest tree spread, height, canopy volume and TCSA, although the yield, yield efficiency and fruiting density were also higher compared to Dashehari. These results aligned with the previous studies on different fruit crops (Smith *et al.* 2004, Dubey *et al.* 2021).

The R × S interaction was found to be significant for the important horticultural traits and yield of the plants. Therefore, the careful selection of rootstock for the growing cultivar could help enhance the quality as well as productivity. The results of the present study clearly identified the vigorous rootstocks. Similar findings were recently documented in mango and other perennial fruit crops, where rootstock-induced differences in hydraulic conductivity and nutrient uptake played a crucial role in determining canopy architecture and productivity (Dubey *et al.* 2021, Shivran *et al.* 2023). Furthermore, rootstocks such as Olour, which exhibited higher fruiting density, indicated the genotype's intrinsic traits related to better assimilate partitioning and reproductive efficiency, aligning with recent studies highlighting the importance of rootstock-mediated hormonal regulation in mango fruit set (Srivastava *et al.* 2019, Kajtar-Czinege *et al.* 2022). The significant rootstock × scion interaction observed for all major growth and yield traits underscored the importance of selecting compatible combinations for orchard establishment. These findings also reiterated the previous findings that scion-rootstock interactions should be a key consideration in breeding and orchard planning for improved productivity and quality (Srivastava *et al.* 2019, Shivran *et al.* 2023).

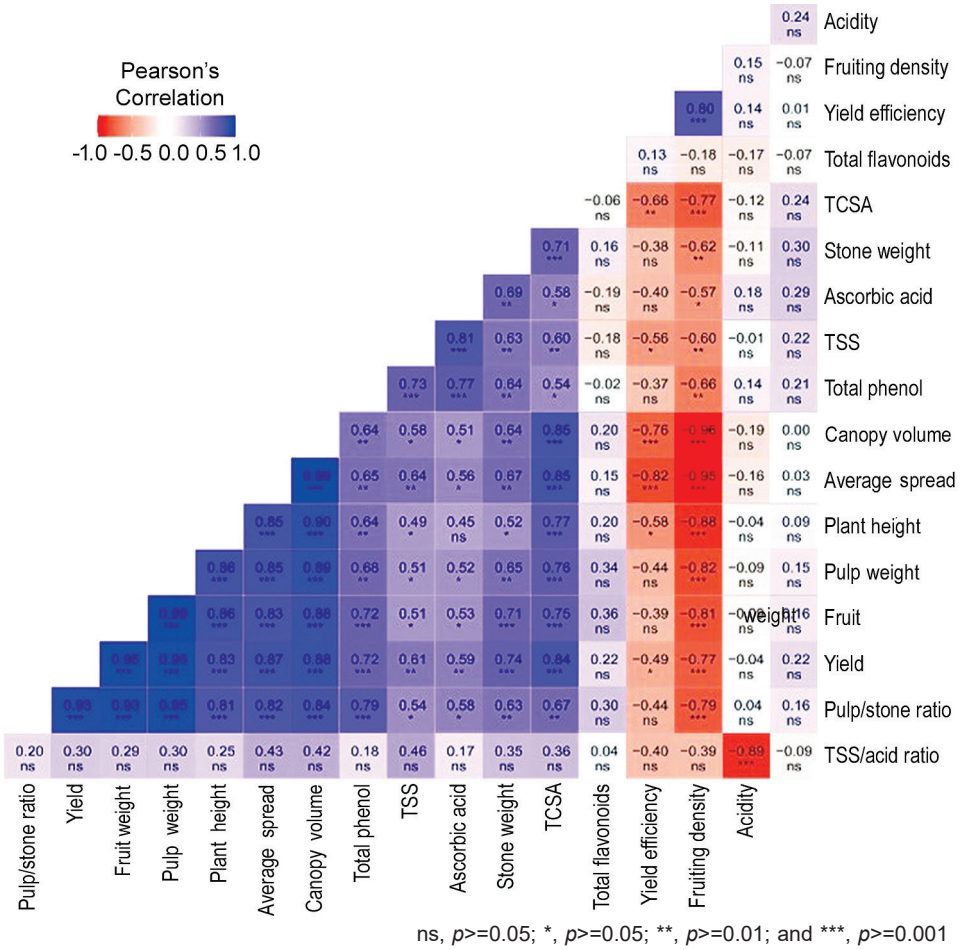

Fig. 1 Pearson correlation for studied traits of mango.
TSS, Total soluble solids; TCSA, Trunk cross-sectional area; ns, Non-significant.

Pearson's correlation for studied traits: Pearson's correlation analysis was used to study the relationship among various physico-chemical, growth and yield traits among mango scion/rootstock combinations (Fig. 1). Fruit weight, pulp weight and pulp/stone ratio were positively correlated with stone weight, ascorbic acid, TSS and total phenol, while these were negatively associated with fruiting density. Ascorbic acid content was positively correlated with TSS, stone weight, TCSA and total phenol but negatively correlated with fruiting density. The pulp/stone ratio had a positive correlation with yield, fruit weight, pulp weight, total phenol, stone weight, TSS and ascorbic acid, which negatively correlated with fruiting density.

The present study revealed a significant correlation between various growth and fruit quality traits in mangoes. Our findings aligned with prior research on citrus (Singh *et al.* 2023) and apple (Valverdi and Kalcsits 2021). These studies similarly emphasised strong associations between the physical characteristics of fruit and the biochemical properties of fruit. Analysing the correlations between mango plant growth and fruit quality traits provided valuable insights into how these relationships influence overall fruit quality. Understanding these associations is critical for breeding programmes focused on enhancing fruit quality, as it enables the identification of traits that can be selected in tandem, ultimately supporting the development of mango cultivars with desirable combinations of growth and quality traits.

Principal component analysis: Multivariate analysis

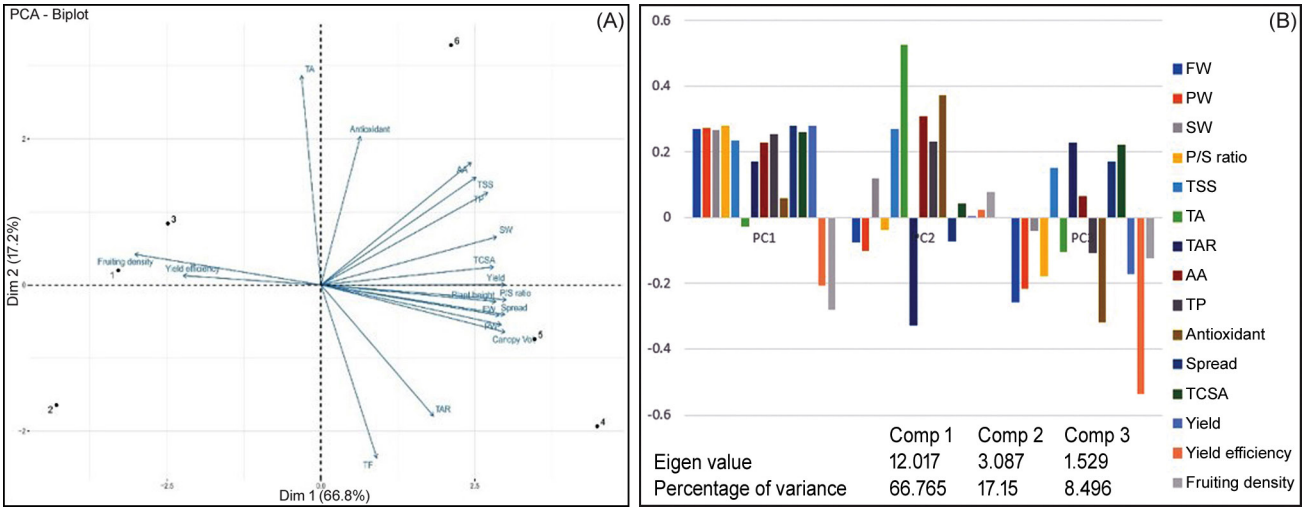

Fig. 2 Principal component analysis of studied morphological traits (A) PCA biplot (B) Rotated component matrix for evaluated traits. FW, Fruit weight; PW, Pulp weight; SW, Stone weight; P/S, Pulp/stone ratio; TSS, Total soluble solids; TA, Titratable acidity; TAR, TSS/acid ratio; AA, Ascorbic acid; TP, Total phenol; TCSA, Trunk cross-sectional area.

using the principal component could afford more information on the similarities and differences among scion/rootstock combinations in mango for the variables under study. PCA was performed using the mean concentration of 17 traits in the six scion/rootstock combinations of mango. Considering a minimum threshold eigen value of one (Hair *et al.* 1998), the three PCs were considered based on eigen value (>1), explaining 92.41% of the total variation among the studied scion/rootstock combinations in mango (Fig. 2). PC1 contributed 66.76% of the total variation, followed by PC2 (17.15%) and PC3 (8.49%). The scion/rootstock combinations of mango for physico-chemical, growth and yield traits namely, fruit weight, pulp weight, stone weight, pulp/stone ratio, TSS, TSS/acid ratio, ascorbic acid, total phenol, total antioxidant activity, tree spread, TCSA and yield with positive loading and yield efficiency and fruiting density were the dominant variables in PC1, thereby causing more significant variability among the scion/rootstock combinations under experiment, while pulp/stone ratio, pulp weight, tree spread and yield with high positive loading and fruiting density and yield efficiency were observed with high negative loading in PC1. In the PC2 (17.15%), titratable acidity, ascorbic acid, antioxidant activity, TSS, total phenol and stone weight contributed to a significant variance with positive loading. In contrast, pulp weight was noticed to have a high negative loading. Furthermore, in the PC3 (10.2%), yield efficiency, antioxidant activity, fruit weight, pulp weight, pulp/stone ratio, titratable acidity, total phenol and yield were found to have negative loading values while TSS/acid ratio, TSS, tree spread and TCSA contributed with positive loading values. As indicated in Fig. 2a, the PCA clearly distinguished the rootstock cultivars combination for both the scion cultivars. The major traits associated with PC1 and PC2 underscored the significance of these traits in observed variations. The multidimensional nature of the PCA underscores the complexity of trait interrelationships and highlights the necessity for a balanced approach in research programmes (Singh *et al.* 2023).

The findings of our study indicated that rootstock had a significant influence on the physico-chemical quality attributes, such as total soluble solids, ascorbic acid, acidity, total phenolics, total antioxidant activity and total flavonoids, apart from well-known growth influence. Olour rootstock imparted higher TSS, ascorbic acid, TA, total phenolics and total antioxidant activity; and it also leads to higher pulp content; hence, were able to improve quality compared to the fruits harvested from the trees grafted on other rootstocks for both scion cultivars. Pusa Aam Moolvrant-2 was able to enhance fruit yield, fruiting density and yield efficiency compared to other rootstocks in both varieties. The overall finding from the present experiment is that Olour rootstock is best for quality and Pusa Aam Moolvrant-2 for yield efficiency and desirable growth traits.

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