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Original Research Paper

Stionic influences on physiology, growth and yield attributes in mango (*Mangifera indica* L.)

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ABSTRACT

The present experiment was carried out to study the influence of the rootstocks (PAM-2, Kurukkan, Olour, K3, PAM-1) on scion cultivars (Pusa Arunima, Pusa Surya and Amrapali) based on the physiological traits, growth parameters, and yield attributes. The maximum yield (80.46 kg tree^{-1}), number of fruits (484.33), and transpiration rate (15.04 µmol H_2O m-^{2}s-^{1}) were found in the Amrapali/Kurukkan combination. Highest photosynthetic rate (10.62 µmol CO_2 m-^{2}s-^{1}) and total chlorophyll (2.03 mg/g) were found in Amrapali/Olour combination. The maximum fruiting density (3.72 m^3), and yield efficiency (0.525 cm^2 TCSA) were found in the Amrapali/PAM-1 combination. Canopy volume (247.31 m^3), and TCSA (358.48 cm^2) were found to be highest in Pusa Arunima/Olour and lowest in Pusa Surya/PAM-1 (72.24 m^3, 147.46 cm^2), respectively. The findings indicated that Olour rootstock was promising for yield and PAM-1 was superior for yield efficiency.

Keywords: Chlorophyll, photosynthetic rate, rootstock, scion, stionic influence

INTRODUCTION

Grafting involves the joining of two different plant genotypes, i.e. a rootstock and a scion in such a way that they unite and grow as a composite plant while maintaining the genotypic identity/characteristics intact for the entire life of that plant. The scion/rootstock interactions and communications are highly complicated and bidirectional, mediated via water relations, nutrient uptake, and level of hormones (Sharma et al*.,* 2016). Furthermore, in arable crops, phenotypic variability usually reveals the genotype x environment interaction (G×E); however, in grafted plants, the phenotype is more complex since it joins two different genotypes, producing R×S×E interactions. As the rootstock and scion are usually genetically diverse from each other, it can result in an interactive and multifactorial effect on plant physiology, growth, yield, and quality. Apart from the well-known stionic influence on growth parameters (Shivran et al., 2023), recent studies have also reported the influence of R×S interaction on fruit quality which remains poorly understood.

Mango, considered as the 'King of fruits', is an important fruit crop in the tropical and subtropical regions of the world. The average national productivity is too low (9.36 tons/ha) compared to other countries, which is mainly attributed to low-density orcharding and lack of standard rootstock apart from other cultivation constraints. In the recent past, a few polyembryony accessions have been tried as rootstock in mangoes (Dayal et al., 2016). However, the influence on fruit quality and nutritional properties still remains unrealized. The identification of appropriate scion-stock combination and complex crosstalk for plant growth, physiology, yield, and fruit quality attributes is a prerequisite for harnessing the untapped potential of rootstock in the mango industry apart from developing a sound scientific basis to understand the complex phenomenon of R×S interaction.

The mango genotypes (Pusa Arunima, Pusa Surya, and Amrapali) were selected based on their contrasting genetic background, growth habit, bearing behaviour, and commercial importance. Amrapali (Dashehari × Neelum) is a compact, precocious, and regular bearer, while, Pusa Arunima (Amrapali × Sensation) and

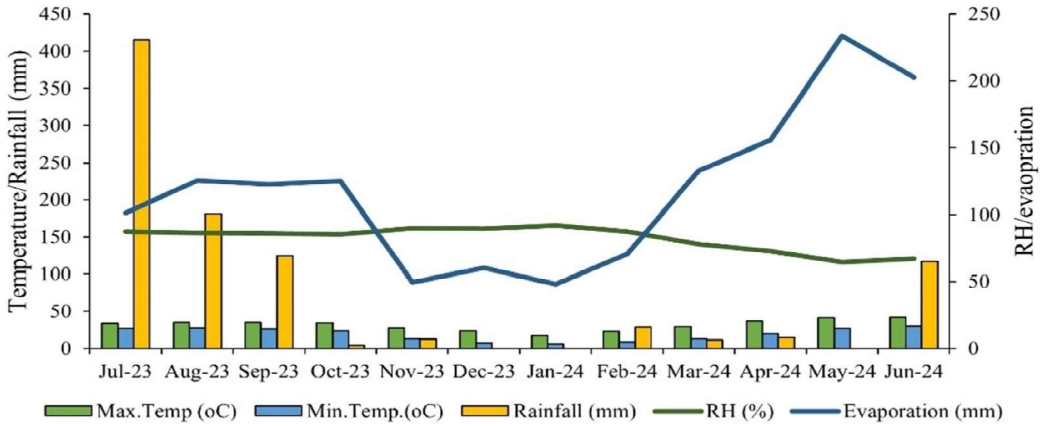

Fig. 1 : Mean monthly weather parameters at the experimental location from July 2023 to June 2024

Pusa Surya (a selection from Eldon) exhibit relatively moderate to vigorous growth with distinct physiological and fruit characteristics. Therefore, the present investigation was carried out to assess the effect of rootstock/scion interaction with reference to physiology, growth, yield, and fruit quality traits in mango.

MATERIALS AND METHODS

The present experiment was conducted with three regular bearer mango scion varieties *viz*., Pusa Arunima, Pusa Surya, and Amrapali grafted onto five polyembryonic rootstocks namely Pusa Aam Moolvrant-1 (PAM-1), K3, Pusa Aam Moolvrant (PAM-2), Kurukkan, and Olour. The selected rootstocks represent diverse polyembryonic mango accessions differing in growth control, adaptability to abiotic stresses, and regional relevance. The grafted trees (16-year age) of each combination were planted at 4 m x 4 m spacing at the experimental orchard, ICAR-Indian Agricultural Research Institute, New Delhi, India and cultural operations as per standard recommendation were followed uniformly in the entire orchard. The weather parameters at the experimental site during July 2023 to June 2024 is presented in the Fig. 1. Soil properties and nutrients status of experimental site is depicted in Table 1.

Table 1 : Soil characteristics of experimental orchard

Soil character	Soil depth (cm)		
	0-15 cm	15-30 cm	30-45 cm
pH (1:2)	7.52	7.30	7.45
EC (1:2) (dS/m)	0.18	0.14	0.11
Organic carbon (%)	0.65	0.47	0.34
N (Kg/ha)	229.50	210.12	184.62
P (Kg/ha)	50.52	46.28	41.68
K (Kg/ha)	285	208	189
Zn (mg/kg)	6.23	2.05	0.78
Fe (mg/kg)	9.21	7.23	6.55
Cu (mg/kg)	1.47	1.26	1.01
Mn (mg/kg)	22.61	13.44	7.15
B (mg/kg)	0.93	0.50	0.51

Estimation of plant growth and yield parameters

Tree height and canopy spread (N-S and E-W) were measured before the onset of flowering. The canopy volume was estimated as CV = $4/3 \times \pi \times a^2b$, as described by (Castle., 1983), where 'a' represents average plant spreads, and 'b' represents half of the tree height. The trunk diameter was measured, 10 cm above the graft union and trunk circumference was measured at 10 cm above and below the graft union. Rootstock-scion index was calculated by dividing the above union circumference to the below union circumference. Trunk cross-sectional area (TCSA) was estimated using the formula, TCSA = $\pi (d/2)^2$, where 'd' = average of N-S and E-W trunk diameter (Rahmati et al., 2015).

Mature fruit from different grafted plants was harvested, and the fruit weight was measured with the help of an electronic digital weighing balance, and the average of 10 fruit weights from different directions was considered as a replication. The number of fruits was counted per tree just before the onset of harvesting. Plant yield (kg plant^{-1}) was obtained through the sum of the entire season crop harvested from each tree. Yield efficiency (YE) was determined as YE = Yield in kg/TCSA (cm^2) (Westwood., 1973).

The fruiting density, i.e. number of fruits per unit canopy volume, was calculated with the help of respective estimates (Smith et al., 2004).

Estimation of leaf chlorophyll and physiological parameters

Chlorophyll content ('a', 'b' and total) was estimated using the method described by Hiscox & Israelstam (1979) with the spectrophotometric method. The physiological parameters *viz*. transpiration rate (E), net photosynthesis rate (A), stomatal conductance (gs), and intercellular CO_2 concentration (Ci) were performed between 9.00 and 11.00 A.M. on fully expanded mature leaves under ambient light and CO_2 levels from different directions (North, South, East and West) during the March with the help of portable infra-red gas analyzer (IRGA) (LCi-SD, ADC Bio Scientific Limited).

Statistical analysis

The experimental data on growth, yield and physiological traits were taken as triplicate where one tree of each combination is considered as single replication. 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 and principal component analysis (PCA) were carried out using R Studio (Version 2022.07.1–554).

RESULTS AND DISCUSSION

Plant growth and yield parameters

The plant growth attributes of grafted mango plants in different scion-rootstock combinations varied significantly with the cultivar, rootstock and rootstock scion factor (Table 2). The plant height of 16-year-old mango plant varied from 3.26-4.46 m. Among the rootstocks evaluated, PAM-1 and PAM2 was the most potential for dwarfness. Among the investigated rootstock x scion interactions, Pusa Arunima showed the least vigour when paired with PAM-1 (3.71 m) and PAM-2 (3.83 m), whereas Pusa Surya and Amrapali had least vigour in graft combination with PAM-1 and K3 rootstock. The stem circumference was also lower for these rootstock-scion combinations compared to the Olour and Kurukkan rootstocks. The results highlight the significant influence of rootstock and scion variety on the growth parameters of mango trees, consistent with previous research in fruit crops (Ikinci et al., 2014). This may be attributed to better water and nutrient uptake efficiency, characteristics of well-adapted rootstocks (Dubey et al., 2021). TCSA is positively related to nutrient transport from the roots to the aerial parts of the tree and the distribution of food materials from production sites to utilization sites. In mango, the result of our study indicated a negative relation between yield efficiency and TCSA; contrary to this, in apples, yield efficiency is associated with TCSA. We observed a positive and significant correlation between TCSA and canopy volume, tree spread, and below and above-union circumference. Our findings showed that the lowest TCSA was in the less vigorous Amrapali / PAM-1 (111.33 cm^2) combination, while the highest was in Pusa Arunima/ Olour (358.48 cm^2), i.e. vigorous combination. Among rootstocks, Olour (267.31 cm^2) exhibited the highest TCSA, and PAM-1 (166.95 cm^2) had the lowest. The consistently lower TCSA observed with the Amrapali/ PAM-1, suggests an additional dwarfing influence of the rootstock. Importantly, a similar trend of reduced TCSA with PAM-1 was observed across other scion cultivars, indicating that the rootstock exerted a growth-modulating effect independent of scion vigour class. These findings are consistent with the results of Kumar et al. (2019) in plum and sweet cherry. Additionally, compatibility between rootstock and scion cultivar is crucial for achieving orchard sustainability and consistently higher yields. This compatibility can also influence fruiting and fruit quality and is often indicated by a rootstock-to-scion ratio close to 1.00. The RSI value of >1 indicates the overgrowth of the scion, i.e. inverted bottleneck as reported as a major incompatibility symptom in different fruit crops (Verma et al., 2000), conversely, RSI value of <1 indicates the undergrowth of scion stem. The present study noted that the Pusa Arunima/ Kurukkan exhibited the minimum RSI (0.90), indicating that the stem thickness of the scion portion is more than the rootstock. Almost all the rootstock scion combinations had RSI values near one, showing the equal growth of rootstock and scion stem in a united plant. The previous studies in ber (Verma et al., 2000) have reported that inverted bottleneck may lead to the dwarfness of fruit plants. However, our study on mango indicated that, despite the undergrowth of rootstock, the Pusa Arunima/Kurukkan combination was vigorous in terms of growth. Persistent under- or overgrowth of rootstock or scion may lead to delayed incompatibility in mango orchards as the perennial fruit orchards remain productive for 50 years or more

Table 2 : Influence of rootstock, scion, and their interaction on plant growth traits in mango

	Plant height (m)				Plant spread (m)			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	3.83^{cd}	3.56^{def}	3.27^{fg}	3.55^{C}	3.48^{gh}	3.74^{efg}	3.99^{e}	3.74^{D}
Kurukkan	4.45^{a}	4.04^{bc}	3.60^{de}	4.03^{A}	4.91^{b}	4.46^{d}	4.51^{d}	4.63^{B}
Olour	4.24^{ab}	4.03^{bc}	3.31^{efg}	3.86^{AB}	5.27^{a}	4.81^{bc}	4.52^{d}	4.87^{A}
K3	4.46^{a}	3.38^{efg}	3.28^{fg}	3.71^{BC}	4.54^{cd}	3.86^{ef}	3.66^{fg}	4.026^{C}
PAM-1	3.71^{d}	3.08^{g}	4.13^{bc}	3.64^{C}	4.89^{b}	3.34^{h}	3.20^{h}	3.81^{D}
Mean	4.14^{A}	3.62^{B}	3.52^{B}		4.62^{A}	4.04^{B}	3.98^{B}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	0.14	0.18	0.31		0.13	0.16	0.28	

	Canopy volume (m^3)				Above union circumference (cm)			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	100.34^{fg}	119.19^{fg}	117.07^{f}	104.39^{E}	36.00^{i}	40.16^{gh}	43.00^{fg}	39.72^{D}
Kurukkan	225.51^{b}	166.38^{e}	154.10^{de}	182.00^{B}	50.33^{cd}	47.3^{de}	48.66^{cde}	48.77^{B}
Olour	247.31^{a}	196.08^{c}	142.59^{e}	195.33^{A}	60.66^{a}	52.667^{bc}	41.66^{fgh}	51.66^{A}
K3	193.45^{c}	102.35^{fg}	95.77^{fg}	129.54^{C}	54.67^{b}	44.66^{ef}	43.00^{fg}	47.44^{B}
PAM-1	186.61^{c}	72.24^{h}	89.27^{gh}	116.04^{D}	51.33^{bcd}	38.66^{hi}	41.30^{fgh}	43.77^{C}
Mean	189.45^{A}	128.37^{B}	118.56^{C}		50.60^{A}	44.70^{B}	43.53^{B}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	8.64	11.15	19.32		1.83	2.36	4.09	

	Below union circumference (cm)				Rootstock-scion index			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	35.66^{h}	42.33^{fg}	44.66^{efg}	40.88^{D}	1.06^{a}	1.10^{a}	1.03^{a}	1.06^{A}
Kurukkan	46.00^{def}	50.33^{cd}	49.66^{cd}	48.66^{B}	0.90^{b}	1.12^{a}	1.01^{ab}	1.01^{A}
Olour	61.33^{a}	55.00^{b}	43.33^{efg}	53.22^{A}	1.01^{ab}	1.00^{ab}	1.05^{a}	1.02^{A}
K3	56.3^{b}	47.67^{de}	47.00^{de}	50.33^{B}	1.03^{ab}	1.01^{ab}	1.02^{ab}	1.02^{A}
PAM-1	52.67^{bc}	41.33^{g}	44.00^{efg}	46.00^{C}	1.02^{ab}	1.08^{a}	1.07^{a}	1.0^{A}
Mean	50.40^{A}	47.33^{B}	45.73^{B}		1.00^{B}	1.06^{A}	1.04^{AB}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	1.95	2.52	4.38		0.056	0.072	0.125	

	Trunk cross section area (TCSA) cm^2			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	212.31^{de}	156.36^{f}	197.85^{e}	188.84^{D}
Kurukkan	237.24^{cd}	219.65^{cde}	160.84^{f}	205.91^{C}
Olour	358.48^{a}	278.96^{b}	164.51^{f}	267.31^{A}
K3	298.76^{b}	297.99^{b}	116.80^{g}	237.85^{B}
PAM-1	242.07^{c}	147.46^{f}	111.33^{g}	166.95^{E}
Mean	269.77^{A}	220.08^{B}	150.27^{C}	
LSD	V	R	V × R	
($p \leq 0.05$)	12.22	15.78	27.33	

V= variety factor; R= rootstock factor; V × R = variety rootstock interaction factor

(Deepak et al., 2019). The findings of the bottleneck in our study are the first reported in mango, which largely remains unknown and is a valuable finding since choosing an incompatible rootstock-scion combination may lead to the production's consequences in long-term orcharding.

In the present study, rootstocks that induce smaller canopies might be useful in high-density planting. A significant impact of the selection of rootstocks on scion growth and resulting in grafted plant in different fruit crops (Sharma et al., 2016; Dubey et al., 2021). The observed variations in the growth of different rootstock scion combinations could be due to the genetic background of the rootstock and the scion and largely depend on the absorption capacity of the rootstock and the subsequent flow of water and minerals to the scion (Dubey et al., 2021), altered balance of carbohydrates, in addition to the alteration in physiological parameters as reported in the present study.

Table 3 : Influence of rootstock, scion, and their interaction on fruit yield of scion/rootstock combinations of mango

	Fruit weight (g)				Yield (kg tree^{-1})			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	239.76^{d}	337.00^{b}	168.96^{h}	248.57^{A}	51.71^{de}	24.48^{hi}	54.01^{de}	43.36^{B}
Kurukkan	215.25^{e}	324.33^{bc}	166.13^{h}	235.23^{B}	68.09^{bc}	23.13^{i}	80.46^{a}	57.23^{A}
Olour	195.94^{efg}	309.00^{c}	213.73^{e}	239.56^{AB}	45.39^{ef}	52.01^{de}	76.37^{ab}	57.80^{A}
K3	192.63^{fg}	383.20^{a}	169.30^{h}	248.37^{A}	38.59^{fg}	34.10^{gh}	55.19^{de}	42.54^{B}
PAM-1	210.43^{ef}	327.53^{bc}	178.70^{gh}	238.88^{AB}	28.61^{hi}	30.78^{ghi}	58.37^{cd}	39.23^{B}
Mean	210.80^{B}	336.21^{A}	179.36^{C}		46.41^{B}	32.85^{C}	64.84^{A}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	8.91	11.50	19.92		4.44	5.74	9.95	
	Fruiting density (number of fruits/m^3 cv)				**Yield efficiency (Yield in kg/TCSA**			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	2.23^{d}	0.69^{fg}	2.89^{bc}	1.93^{A}	0.243^{bcd}	0.158^{efg}	0.274^{bc}	0.224^{B}
Kurukkan	1.40^{e}	0.43^{g}	3.17^{ab}	1.67^{AB}	0.287^{b}	0.106^{g}	0.506^{a}	0.299^{A}
Olour	0.94^{efg}	0.85^{efg}	2.52^{cd}	1.44^{B}	0.127^{fg}	0.188^{def}	0.467^{a}	0.260^{AB}
K3	1.05^{ef}	0.87^{efg}	3.39^{ab}	1.77^{A}	0.131^{fg}	0.115^{g}	0.474^{a}	0.239^{B}
PAM-1	0.72^{fg}	1.33^{e}	3.72^{a}	1.92^{A}	0.118^{fg}	0.208^{cde}	0.525^{a}	0.283^{A}
Mean	1.27^{B}	0.83^{C}	3.14^{A}		0.181^{B}	0.155^{B}	0.448^{A}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	0.24	0.32	0.55		0.032	0.042	0.072	

V= variety factor; R= rootstock factor; V × R = variety rootstock interaction factor

Yield traits

The rootstock and their interaction significantly influenced yield traits in mango (Table 3). Among the rootstocks, PAM-2 and K3 consistently exhibited the highest fruit weight across all varieties with the Pusa Surya/K3 (383.20 g) combination showing the highest fruit weight; on the other hand, Amrapali/Kurukkan (166.13 g) produced the smallest fruit. Interestingly, the Amrapali/Olour (213.73 g) combination had a higher fruit weight than other Amrapali/rootstocks combinations, suggesting that vigorous rootstocks like Olour contribute to larger fruit development in Amrapali. In terms of overall yield per tree, Amrapali grafted onto Olour (57.80 kg tree^{-1}) and Kurukkan (57.23 kg tree^{-1}) registered the highest, indicating that vigorous rootstocks are associated with higher yield/ plant in mango. Kurukkan and Olour were particularly effective in enhancing yield across all varieties, while Amrapali consistently outperformed Pusa Arunima and Pusa Surya in terms of yield/tree, suggesting its inherent potential for higher productivity.

The results showed that the fruiting density was higher in the least vigorous combinations, namely, Amrapali/ PAM-1 (3.72 m^3 cv), Amrapali/K3 (3.39 m^3 cv), and Amrapali/Kurukkan (3.17 m^3 cv), hence demonstrating the higher productivity potential of dwarf plants. In contrast, combinations involving Pusa Surya (0.43 m^3 cv), particularly with Kurukkan, exhibited the lowest fruiting density. The dwarfing rootstocks PAM-2 (1.93 m^3 cv), PAM-1 (1.92 m^3 cv), and K3 (1.77 m^3 cv) showed higher fruiting density than the vigorous Olour (1.44 m^3 cv) rootstock. Yield efficiency was highest in the Amrapali (0.448 cm^2 TCSA) variety, especially when paired with Kurukkan, Olour, K3, and PAM-1, suggesting the differential behavior of a variety with different rootstock genotypes, which is crucial for improving orchard productivity. Kurukkan, Olour, and PAM-1 were the most efficient rootstocks across the variety, while Amrapali remained the top-performing variety for yield efficiency. These findings aligned with the studies on citrus, grapes, apple, pear, plum, cherry, and apricot (Kumar et al., 2019; Sharma et al., 2016).

Table 4 : Influence of rootstock, scion, and their interaction on leaf physiological attributes of scion/ rootstock combinations of mango

	Photosynthetic Rate A (Pa) µmol CO_2 $m^{-2}s^{-1}$				Stomatal Conductance (gs) mol H_2O $m^{-2}s^{-1}$			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	8.15^{cde}	8.43^{bcde}	10.59^{a}	9.06^{A}	0.098^{gh}	0.130^{bcd}	0.138^{b}	0.122^{A}
Kurukkan	8.66^{abcde}	7.90^{de}	10.43^{ab}	9.00^{A}	0.157^{a}	0.114^{defg}	0.096^{hi}	0.122^{A}
Olour	9.92^{abcd}	6.61^{e}	10.62^{a}	9.05^{A}	0.103^{efgh}	0.077^{j}	0.118^{cdef}	0.099^{B}
K3	10.03^{abc}	7.39^{e}	8.02^{cde}	8.48^{A}	0.098^{gh}	0.080^{ij}	0.102^{fgh}	0.093^{B}
PAM-1	7.45^{e}	8.21^{cde}	10.41^{ab}	8.69^{A}	0.128^{bcd}	0.120^{cde}	0.133^{bc}	0.127^{A}
Mean	8.84^{B}	7.71^{C}	10.018^{A}		0.116^{A}	0.104^{B}	0.117^{A}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	0.92	1.196	2.071		0.0077	0.0099	0.0172	
	Intercellular CO_2 (Ci) µmol CO_2/mol				**Transpiration Rate E (Tr) µmol H_2O $m^{-2}s^{-1}$**			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	271.66^{bc}	260.83^{cde}	247.50^{efgh}	260.00^{B}	9.25^{h}	9.80^{gh}	13.85^{abc}	10.96^{CD}
Kurukkan	269.66^{bc}	241.33^{fgh}	193.33^{i}	234.77^{C}	12.21^{cdef}	12.93^{bcd}	15.04^{a}	13.39^{A}
Olour	267.16^{bcd}	251.50^{defg}	233.50^{h}	250.72^{B}	12.76^{bcde}	10.56^{fgh}	14.36^{ab}	12.56^{AB}
K3	199.00^{i}	234.66^{gh}	279.33^{b}	237.66^{C}	10.73^{efgh}	8.71^{h}	10.68^{fgh}	10.04^{D}
PAM-1	316.00^{a}	272.16^{bc}	258.00^{cdef}	282.05^{A}	11.48^{defg}	11.85^{cdefg}	12.12^{cdef}	11.82^{BC}
Mean	264.70^{A}	252.10^{B}	242.33^{C}		11.29^{B}	10.77^{B}	13.21^{A}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	8.03	10.36	17.95		0.92	1.19	2.07	
	Instantaneous water use efficiency (WUEi) µmol CO_2 per H_2O				**Carboxylation capacity**			
Genotype	Pusa Arunima	Pusa Surya	Amrapali	Mean	Pusa Arunima	Pusa Surya	Amrapali	Mean
PAM-2	0.884^{ab}	0.881^{ab}	0.768^{abc}	0.844^{A}	0.032^{ef}	0.037^{def}	0.037^{bc}	0.035^{AB}
Kurukkan	0.710^{bc}	0.609^{c}	0.694^{bc}	0.671^{B}	0.035^{def}	0.035^{def}	0.049^{a}	0.039^{A}
Olour	0.775^{abc}	0.626^{c}	0.740^{abc}	0.713^{B}	0.036^{cde}	0.035^{f}	0.042^{abc}	0.036^{AB}
K3	0.930^{a}	0.863^{ab}	0.751^{abc}	0.848^{A}	0.050^{ab}	0.028^{def}	0.036^{ef}	0.037^{AB}
PAM-1	0.656^{c}	0.704^{bc}	0.864^{ab}	0.741^{AB}	0.025^{f}	0.036^{ef}	0.034^{bcd}	0.031^{B}
Mean	0.790^{A}	0.736^{A}	0.763^{A}		0.034^{B}	0.030^{B}	0.042^{A}	
LSD	V	R	V × R		V	R	V × R	
($p \leq 0.05$)	0.085	0.110	1.191		0.0045	0.0058	0.010	

V= variety factor; R= rootstock factor; V × R = variety rootstock interaction factor

Physiological parameters

The physiological parameters of 15 scion/rootstock combinations of mango were studied for grafted plant i.e. from leaf of scion. The investigated physiological attributes showed significant variations in the present study (Table 4). The findings indicate that scion and rootstock, both individually and in combination (S×R), play an important role to influence the physiological efficiency of grafted mango plants which is in line with the previous findings in different fruit crops *viz.*, mango (Dayal et al., 2016; Vittal et al., 2023), and citrus (Ikinci et al., 2014).

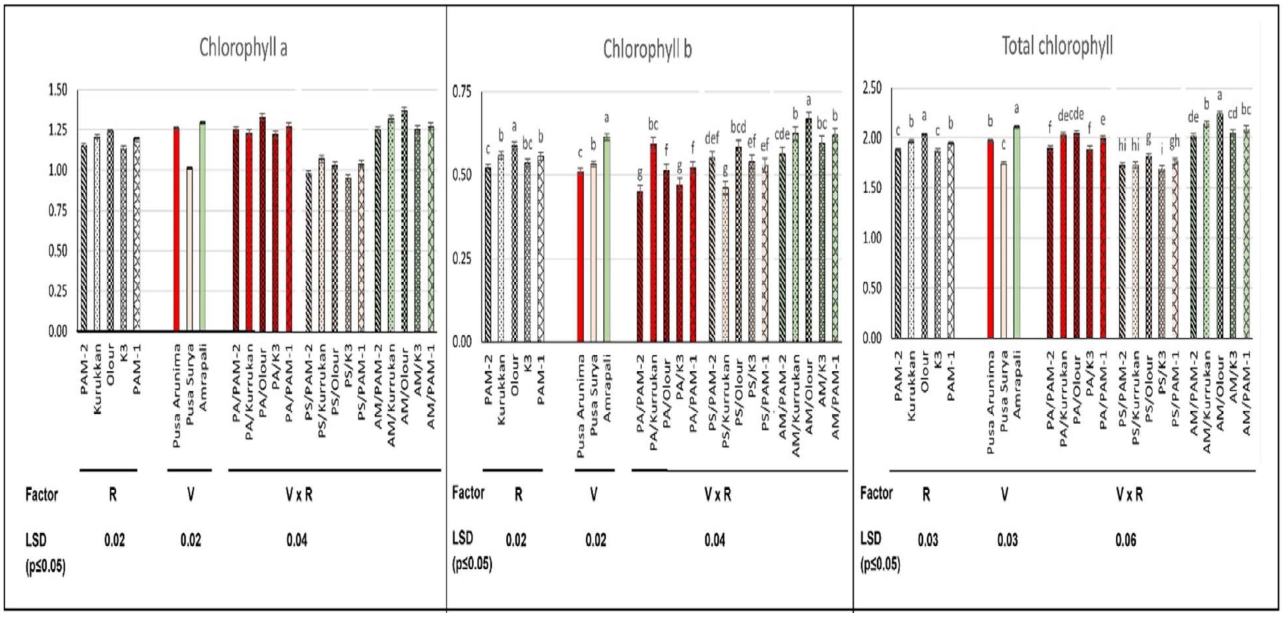

Fig 2 : Influence of rootstock on chlorophyll in different scion/rootstock combinations of mango. R = rootstock; V= variety; V×R = variety rootstock interaction factor

The mean value for chlorophyll pigments was higher in the vigorous rootstock Olour (2.03 mg/g) and Kurukkan (1.96 mg/g) compared to the dwarfing PAM-1 (1.94 mg/g), PAM-2 (1.87 mg/g), and K3 (1.87 mg/g) rootstocks, while among the varieties Amrapali (2.10 mg/g) leaf tissue contained the higher Chlorophyll-a and total chlorophyll followed by Pusa Surya (1.74 mg/g) and least in Pusa Arunima (1.96 mg/g) (Fig. 2). Vigorous rootstocks such as Olour and Kurukkan contributed to higher chlorophyll levels, and Amrapali had inherent potential for higher chlorophyll content, although it varies with different rootstocks.

Similarly, the stomatal conductance, affecting the gas exchange and water vapor loss, was also higher in combinations involving vigorous rootstocks such as Kurukkan, supporting increased transpiration and higher growth potential in these combinations (Das et al., 2016). The results also indicate that rootstock vigour influenced intercellular CO_2 concentration, with less vigorous rootstocks, such as PAM-1 (0.127 mol H_2O $m^{-2}s^{-1}$) and PAM-2 (0.122 mol H_2O $m^{-2}s^{-1}$), showing higher intercellular CO_2 levels. This suggests an enhanced CO_2 assimilation potential in these combinations, which is particularly beneficial in high-density planting systems, where smaller plant sizes and more efficient photosynthesis are important parameters (Das et al., 2016). Conversely, combinations involving vigorous rootstocks such as Amrapali/Kurukkan (0.096 mol H_2O $m^{-2}s^{-1}$) demonstrated lower intercellular CO_2, reinforcing that less vigorous rootstocks are better suited for intensive cultivation practices. Our study showed that combinations with less vigorous rootstocks, such as K3 and PAM-2, maintained lower transpiration rates in addition to the WUEi, suggesting that these rootstocks could enhance water-use efficiency in high-density orchards (Vittal et al., 2023). This is consistent with previous findings in mango and other fruit crops. Lower-vigour rootstocks can improve WUEi by maintaining efficient water balance, particularly under water-limited conditions. Carboxylation capacity was also highest in vigorous combinations, particularly when Amrapali grafted onto vigorous rootstocks such as Kurukkan and Olour. This supports previous studies emphasizing the need for careful rootstock selection to balance vigour and productivity in high-density orchards (Vittal et al., 2023).

Correlation among the studied traits

Pearson's correlation analysis (Fig. 3) revealed important relationships among growth, yield, and physiological traits in mango scion/rootstock combinations. Positive correlations were noted among key growth parameters, such as plant height, canopy volume, and trunk cross-sectional area (TCSA). In contrast, the rootstock-scion index negatively correlated with growth traits, underscoring its role in

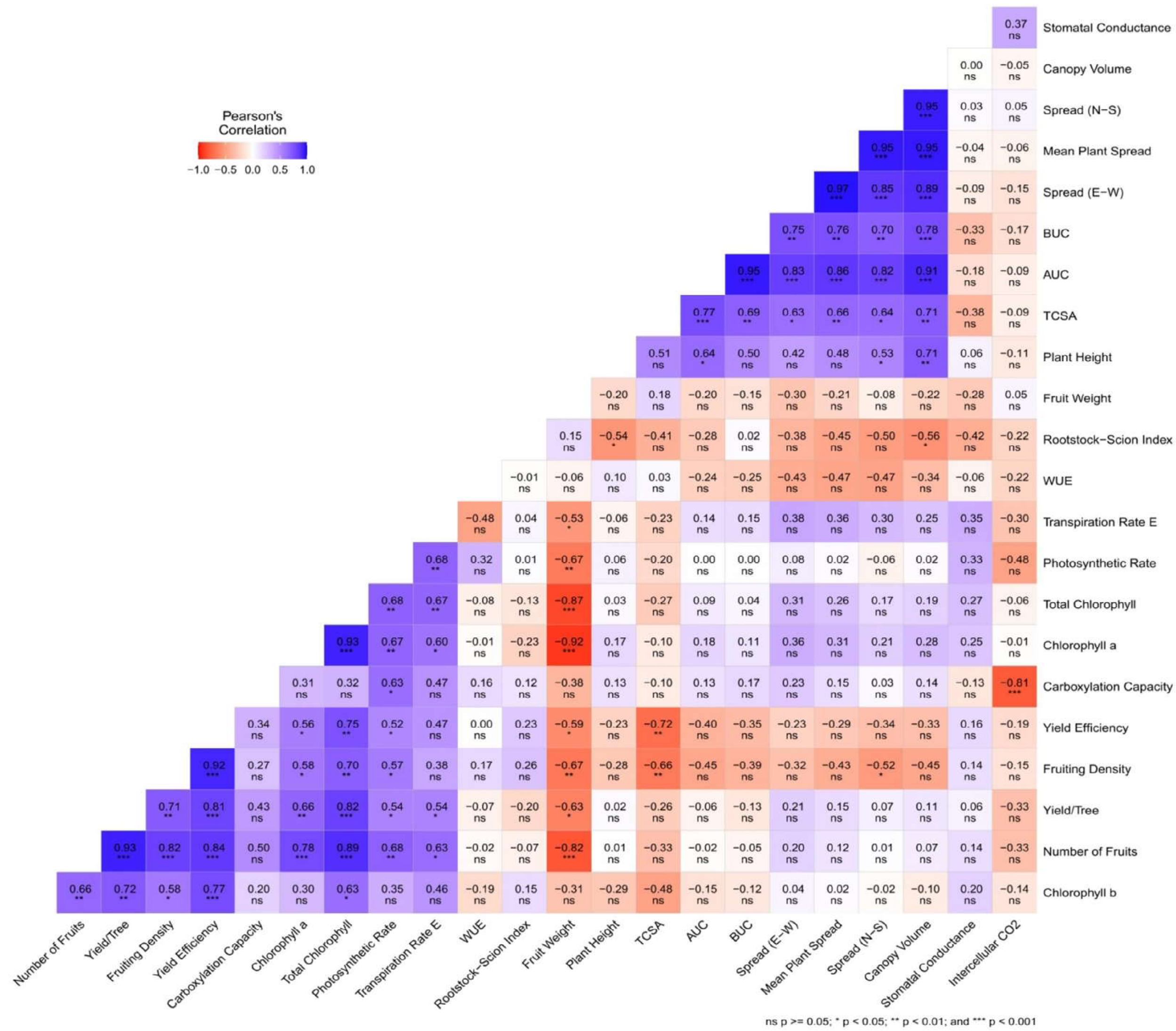

Fig. 3 : Pearson correlation between studied for growth, yield, and physiological parameters

controlling vigour in dwarfing rootstocks. Positive associations among physiological traits like chlorophyll content, photosynthetic rate, and transpiration rate suggest that higher chlorophyll levels enhance photosynthetic efficiency, which in turn enhance the vigour of the plant. A negative correlation between carboxylation rate and intercellular CO_2 concentration indicates a trade-off between photosynthesis and CO_2 assimilation. It highlighted the need for a balanced approach in rootstock selection-related traits, such as yield efficiency and fruiting density, showed positive correlations, while fruit weight had an inverse relationship with these traits, suggesting that increased fruit density may reduce fruit size, as observed in previous studies (Dubey et al., 2021).

Principal component analysis

A total of 5 PCs were considered having a minimum threshold eigen value of one the three PCs were, explaining 87.26% of the total observed variance in the present study (Fig. 4). The PCA biplot showed the locations of different scion/rootstock combination based on similarity along the major axis. The acute angle ($\leq 90^o$) between variables indicated the positive association among the variables and vice versa. A high vector length for variables like, canopy volume, fruit weight, plant spread, fruiting density, total chlorophyll, TCSA, and number of fruits in the PCA biplot indicated the presence of large variations for these traits under the influence of scion/rootstock combinations in mango.

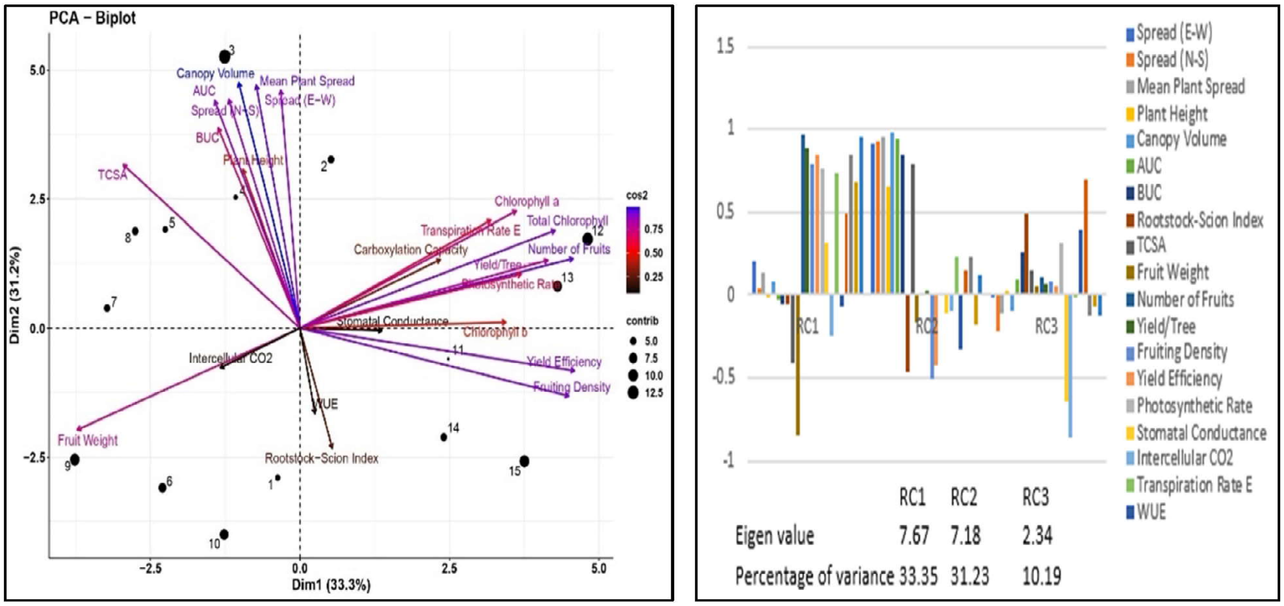

Fig. 4 : Principal component analysis of growth, yield, and physiological traits (a) PCA biplot (b) rotated component matrix for evaluated traits

CONCLUSION

The mango rootstocks Olour and Kurukkan were found vigorous, while, PAM-1, PAM-2 and K3 reduced the growth of the scion significantly which is desirable for high density plantings. The rootstock Kurukkan tended to have over/under growth at graft union which may results in delayed graft incompatibility consequences in the later stage of fruit orchard as reported with Pusa Surya.

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