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INFLUENCE OF ROOTSTOCK ON PLANT GROWTH, PRODUCTIVITY AND FRUIT QUALITY CHARACTERISTICS OF KINNOW MANDARIN UNDER INDIAN SUB-TROPICS

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Citrus is being cultivated on 1.10 million hectares in India with an annual production of 14.61 million metric tons (Anonymous 2023a). Mandarins have an important position in India and occupy largest area among citrus fruits (Ladaniya, 2010). These fruits are being commercially cultivated in Maharashtra, Madhya Pradesh, Andhra Pradesh, Punjab, Haryana, Rajasthan, and Uttar Pradesh. They occupy an area of 0.48 million hectares with an annual production of 6.39 million metric tons (Anonymous, 2022). In Punjab state, Kinnow mandarin ranks first by sharing 47.9 per cent of the total area (99.75 thousand hectares) and 56 per cent of the total fruit production (22.18 lacs MT) of the state (Anonymous, 2023b). Mandarins with better quality of fruit are produced in Punjab due to warm days and cooler nights during winter coincide with the maturity and ripening, which are conducive for good quality fruit production.

Rough Lemon (*Citrus jambhiri* Lush) is a vigorous rootstock which has highly extensive root system and widely used for Kinnow mandarins (Chahal, 2023). Undoubtedly, an adaptation of the 'Rough Lemon' rootstock in Punjab helped to popularize Kinnow mandarin. However, 'Rough Lemon' rootstock is highly vulnerable to '*Phytophthora'*, which results in poor productivity especially under neglected conditions. Furthermore, most of the fruit crops are perennial in nature and are prone to several biotic and abiotic stresses during their growth and development (Pujar *et al.,* 2017). The potential to upgrade citrus rootstock is limited due to heterozygosity, sexual incompatibility, apomixes, nucellar polyembryony, and ovule sterility in citrus. Thus, the feasibility of prominent rootstocks for Kinnow mandarin is need of hour. Various aspects like stock-scion compatibility, longer growing period, high productivity, reduction in size without affecting yield, and resistance to biotic and abiotic stresses are needed to be tested under Indian sub-tropical conditions. The size and vigour of the citrus plant can be reduced by the use of dwarfing rootstock for high-density plantation (Mota *et al.,* 2019). Furthermore, it had been reported that the fruit colour in citrus is also influenced by the rootstock (Ladaniya, 2010). The attractive orange colour of the harvested fruit also stimulates the perception of freshness and hence, it facilitates the marketing of the produce. Besides other factors, rootstocks in citrus provide farmers more options to boost fruit quality and productivity (Mallick, 2019). Rootstock influences growth and development of scion variety in various aspects like juvenility, productivity, fruit quality, and tolerance to biotic and abiotic stresses (Gill and Kaur, 2017). Many of the researchers have reported a significant effect of rootstock on the fruit quality and yield in citrus (Singh *et al*., 2017; Rattanpal *et al.,* 2017; Pandey *et al*., 2022; Chahal, 2023). More recently, it had been reported that rootstocks viz. 'Swingle', 'Sour Orange', 'Carrizo', 'X-639' and 'Schaub' exhibited tolerance to *P. nicitianaae* (Singh, 2024).

Undoubtedly, there is no controversy over the importance of citrus rootstock for better citrus production. But, new rootstock adoption is an essential task for addressing citrus production problems and meeting market demands for higher fruit quality (Yildiz *et al.,* 2013). In view of this, during the last years, new rootstocks have been introduced in Punjab. These rootstocks need to be evaluated on 'Kinnow' mandarin compared to existing rootstocks under Northwestern Indian conditions. So, the present investigation was undertaken to evaluate the performance of newly introduced rootstocks for 'Kinnow' mandarin under north Indian conditions in field and Punjab in particular.

The experiment was conducted at the Punjab Agricultural University's (PAU) Fruit Research Farm in Ludhiana, Punjab (India). The research site is located at the latitude of 30° 54' N and longitude 75° 48' E. The location is 247 m above mean sea level, and the climate of the area is typically sub-tropical. The significant amount of annual rainfall is received from July to September. Kinnow mandarins budded on six rootstocks, namely 'Kuharske', 'Rich 16-6', 'Swingle', 'Troyer', 'Carrizo', and 'Rough Lemon', were used in the investigation. The experimental plants were planted at a spacing of 6m x 3m. All the recommended package of practices of PAU for the cultivation of Kinnow mandarin were followed (https://www.pau.edu/content/ccil/pf/pp_fruits.pdf). The experiment included five 'Kinnow' plants on each of the six rootstocks, planted in accordance to

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randomized block design.

Randomly selected five 'Kinnow' mandarin plants on these rootstocks were examined for plant morphological traits, plant productivity and fruit physico-chemical traits as per standard procedure (AOAC, 2005) of fruits during 2020-21. The ascorbic acid content was determined using the 2, 6-dichlorophenol indophenol technique (AOAC, 2005), and the values were represented in mg/100 ml of juice. Fruit juice content was estimated on a W/W basis. The entire endocarp of the fruit was crushed, and the juice was drained using a muslin cloth. The percentage of fruit juice was worked out on the basis of whole fruit weight. The volume of the plant canopy was calculated using plant height and spread measurements. The plant was assumed to be one half of prolate spheroid, and volume was calculated by the following equation:

Volume = 0.524 × height × plant spread^2.

The Citrus Color Index (CCI) of fruit epicarp, pulp, and juice were recorded with the help of self-contained colour estimation (IPGRI, 1999). The chromicity values were measured with Hunter Lab colorimetric system (Hunter, 2008). The data collected for various treatments during the trial were evaluated according to Randomized Block Design (Gomez and Gomez, 2010). Analysis of variance was done using software SAS 9.3 version.

'Kinnow' plants budded on different rootstocks showed significant variation concerning rootstock diameter (Table 1). The data showed that rootstock diameter (110.2 mm) and scion diameter (101.0 mm) were maximum in Kinnow plants budded on 'Rough Lemon'. However, the minimum rootstock diameter (84.0 mm) and scion diameter (62.2 mm) were recorded with 'Swingle' rootstock. The ratio of rootstock and scion diameter is crucial in determining the degree of compatibility in stionic combinations. 'Carrizo' had the highest mean rootstock and scion diameter ratio (0.94), followed by Rough Lemon (0.91), and these were significantly higher than all other rootstocks.

The variation in rootstock diameter of Kinnow on different rootstocks might be due to decrease in plant growth due to bud union resistance to water transport and xylem anatomical characteristics, particularly the number and diameter of vessels and carbohydrate distribution (Forner-Giner *et al.,* 2014). Similarly, variation in scion diameter among different rootstock combinations might be due to differential xylem anatomical characteristics, carbohydrate translocation, and different growth responses of different rootstocks. Likewise, Bassal (2009) also reported the largest scion circumference (40.2 cm) of Kinnow scion on 'Sour Orange' rootstock with substantial variations among other rootstocks. The stock and scion ratio of the budded plant represents the differences in the relative growth rates of each plant fraction viz., rootstock and scion. It also indicates the compatibility of stock and scion and it is also used as a stock and scion affinity indicator (Roose *et al.,* 1989). The value closer to 1.0 indicated the better compatibility between stock and scion.

The maximum mean plant height was recorded on 'Kuharske' (3.2 m) followed by 'Carrizo' (2.8 m), 'Rich 16-6' (2.8m), 'Rough Lemon' (2.8m) and 'Troyer' (2.5m) (Table 1). However, the minimum mean plant height was recorded on 'Swingle' (1.4 m) rootstock. The maximum plant spread was recorded on 'Rough Lemon' (2.68 m^2) and 'Carrizo' rootstocks followed by 'Rich 16-6' (2.62 m^2), 'Kuharske' (2.45 m^2), and 'Troyer' (2.18 m^2). However, minimum plant spread was recorded on 'Swingle' (1.65 m^2). Similarly, maximum canopy volume of Kinnow was recorded on 'Carrizo' rootstock (10.89 m^3) followed by 'Rich 16-6' (10.54 m^3), 'Kuharske' (10.51 m^3), and 'Rough Lemon' (10.51 m^3).

The results are supported by the fact that the dwarfing rootstocks have been linked to lower leaf and stem water potentials in grafted scions than those grafted onto vigorous rootstocks. This was most likely due to high hydraulic conductivity resistance, which might cause water deficit in leaves during periods

Table 1. Effect of different rootstocks on plant growth characteristics of Kinnow mandarin

Rootstock	Rootstock diameter (mm)	Scion diameter (mm)	Stock/Scion diameter ratio	Plant height (m)	Plant spread (m^2)	Plant canopy volume (m^3)
Kuharske	104.3ab*	88.1c	0.84c	3.2a	2.45ab	10.51a
Rich 16-6	105.7ab	90.5bc	0.85bc	2.8ab	2.62a	10.54a
Swingle	84.0c	62.2d	0.75d	1.4c	1.65c	2.25c
Troyer	96.4bc	81.7c	0.85bc	2.5b	2.18b	6.49b
Carrizo	106.0ab	100.1ab	0.94a	2.8ab	2.68a	10.89a
Rough Lemon	110.2a	101.0a	0.91ab	2.8b	2.68a	10.51ab
CD (*p=0.05*)	12.84	9.95	0.07	0.40	0.42	3.45

*Within a column means followed by different alphabets differ significantly

of high evaporation period (Martínez-Alcántara *et al.,* 2013). As a result, dwarfing rootstocks have trouble transporting water from the soil to the stems (Perez-Perez *et al.,* 2005). Similarly, in current studies, the reduced growth attributes in Kinnow plants on 'Swingle' and 'Troyer' rootstocks might be due to the rootstock's poor nutrient accumulating activity and higher phenol content accumulation in the scion leaf, resulting in low vigour of scion variety.

The differences in canopy volume of Kinnow on different rootstocks might be due to the differential bud union resistance to water transport and the number and diameter of vessels, which restrict plant development. Additionally, carbohydrate distribution is an important constraint in plant response (Forner-Giner *et al.,* 2014), as a result, the TCSA is commonly thought to be strongly linked to plant weight and canopy thickness (Yildirim *et al.,* 2010). Aviles *et al.* (2010) also reported differential canopy plant growth responses in 'Changsha x English Okitsu' Satsuma mandarin on small hybrid rootstock (14.9 m^3) and 'Flying Dragon' trifoliate rootstock (2.3 m^3).

The maximum mean fruit weight (Table 2) was recorded on 'Carrizo' (186.25 g) followed by 'Rough Lemon' (168.58 g). However, a significantly lower fruit weight was recorded on 'Kuharske' (134.4 g). Similar findings were reported by Aviles *et al.* (2010) that rootstock had a major impact on fruit weight. They reported a higher fruit weight of variety 'Orlando' (213 g) budded on 'Carrizo' citrange rootstocks. The data showed that a maximum number of Kinnow fruits per plant (377.4) was recorded in 'Rough Lemon' followed by 'Carrizo' (366.6) (Table 2). However, a significantly lower number of fruits per plant (150.8) were recorded on 'Swingle'. Similarly, the maximum mean fruit yield per plant was recorded on 'Carrizo' (68.27 kg/plant) followed by 'Rough Lemon' (63.62 kg/ plant). However, a considerably lower mean fruit yield per plant was recorded on 'Swingle' (22.0 kg/plant). The lower mean fruit yield on 'Swingle' is probably due to their small TCSA (Yildirim *et al.,* 2010), restricting the uptake of nutrients to the growing scion. The reduced canopy volume of the plant leads to a lower yield per plant. Furthermore, flowering inhibition is inextricably linked to juvenility and alternative bearing, and it also has clear implications for active volumes. The variation in the fruit yield of Kinnow mandarin budded on different rootstocks indicated the influence of rootstock on fruit yield and their quality variables. Gill *et al*. (2016) investigated the impact of three rootstocks namely 'Carrizo' citrange, 'Volkameriana', and 'Rough Lemon' on Daisy mandarin. They reported that fruit yield per plant was the highest on 'Volkameriana' rootstock, while 'Carrizo' rootstock yielded larger fruits.

The maximum mean yield efficiency was recorded on 'Swingle' (9.77 kg/m3) followed by 'Carrizo' and 'Rough Lemon'. On the other hand, the 'Kuharske' rootstock had the lowest yield efficiency (3.73 kg/m^3). It had been reported that rootstocks having higher yield efficiencies were ideal for high-density plantation to compensate for the decreased productivity of individual plants (Forner-Giner *et al.,* 2014). According to Georgiou (2000), Nova mandarin yield efficiency was the highest on 'Carrizo' citrange and the lowest on 'Sour Orange'. Similarly, Aviles *et al.* (2010) also reported that the yield efficiency of 'Okitsu' mandarin was substantially higher in plants budded onto the 'Flying Dragon', while 'Sunki' mandarin had the lowest yield efficiency.

Kinnow fruits produced on 'Carrizo' (Table 2) were the longest (62.1 mm) and having maximum fruit diameter (77.5 mm). The maximum mean rind thickness was recorded on 'Swingle' (3.94 mm) and it was at par with 'Troyer' (3.62 mm) and 'Carrizo' (3.34 mm). The minimum fruit diameter (68.7 mm), fruit length (54.0mm) and rind thickness (3.04 mm) were recorded on 'Kuharske'. Fruit size is a critical factor for citrus growers and it determine whether the fruit is to be sold fresh or processed. In the market, medium to

Table 2. Effect of different rootstocks on fruit physical characteristics of Kinnow mandarin

Root stock	Fruit weight (g)	Fruit number per plant	Fruit yield (kg/plant)	Yield efficiency (kg/m^3)	Fruit diameter (mm)	Fruit length (mm)	Rind thickness (mm)
Kuharske	134.4c*	292.4b	39.29b	3.73d	68.7d	54.0d	3.04c
Rich 16-6	167.54b	364.0a	60.97a	5.78bc	73.07bc	58.5bc	3.11c
Swingle	146.3bc	150.8cd	22.0bc	9.77a	69.4cd	56.3cd	3.94a
Troyer	154.0b	210.8c	32.46bc	5.00bc	73.9ab	60.6ab	3.62ab
Carrizo	186.25a	366.6a	68.27a	6.26b	77.5a	62.1a	3.34bc
Rough Lemon	168.58a	377.4a	63.62a	6.05b	69.3cd	57.6bc	3.226bc
CD (*p=0.05*)	22.1	70.2	20.2	2.3	4.20	3.15	0.43

*Within a column means followed by different alphabets differ significantly

large-sized fruit yielded the highest returns (Hussain *et al.,* 2013). The results show that the fruit diameter increases with fruit cell differentiation which generally occurs after the stoppage of cell division followed by a period of cell enlargement (Agusti, 2000). Georgiou (2000) discovered that rootstocks substantially impact fruit diameter, with fruits from Estes Rough Lemon (68.8 mm) having the largest diameter. The fruit rind thickness varied with rootstock used and higher rind thickness was recorded on 'Swingle', 'Troyer', and 'Carrizo' rootstocks than other rootstocks. In a similar study, Sharma *et al.,* (2002) reported that thickly peeled (4.9) Kinnow mandarin fruits on 'Rough Lemon' and 'Karna Khatta' rootstocks whereas, those grown on 'Troyer' and 'Carrizo' rootstocks were thinly peeled (4.6 mm). This can be attributed to cell division during the early stages of fruit development, caused mainly by the thickness of the peel tissue (Dalal *et al.,* 2013).

The maximum mean TSS content (Table 3) was recorded in fruits on 'Carrizo' (10.1°Brix) followed by 'Rough Lemon' (9.6°Brix). However, significantly lower TSS was recorded in Kinnow fruits on 'Kuharske' and 'Troyer' (9.0°Brix). Kinnow mandarin budded on 'Carrizo' rootstock recorded significantly lower fruit acidity (0.78 %) followed by 'Rough Lemon' rootstock (0.81 %). However, significantly higher fruit acidity was recorded on 'Swingle' (1.06 %) and 'Kuharske' (1.04 %). The maximum fruit TSS/acid ratio was recorded in Kinnow plants budded on 'Carrizo' (12.94) and 'Rough Lemon' (11.85) rootstocks. However, significantly lower TSS/acid ratio (8.65) was recorded in Kinnow fruits budded on 'Kuharske'. A significantly higher TSS/acid ratio on 'Carrizo' and 'Rough Lemon' rootstocks indicated the superiority of these rootsocks for Kinnow fruits.

The ripeness index (RI), which relates to the solid soluble content of fruit juice measured in °Brix, is the most widely used method for estimating the maturity level of citrus fruits. As a result, citrus fruit flavour and palatability differ depending on TSS levels and herbal or bitter juice constituents. Likewise, Sharma *et al.* (2002) also reported higher TSS in Kinnow on Troyer rootstock than on Rough Lemon rootstock. Fruit acidity is the most widely used method for determining citrus fruit maturity. The acid content of fruit is known to decrease as the fruit matures. The use of acids in the respiratory fruit process might also account for the decrease in acid content (Nagar, 1994). A similar influence of rootstock on fruit acidity has already been reported by Hussain *et al.* (2013), who reported a substantial difference in titratable acidity in citrus fruits on *Holansis trifoliate* orange, AA18 trifoliate orange and 'Carrizo' citrange rootstocks.

The data in table 3 revealed that maximum ascorbic acid was recorded on 'Rough Lemon' (31.10 mg/100ml juice) and 'Carrizo' (30.25 mg/100ml juice). Whereas, the minimum ascorbic acid was recorded on 'Troyer' (24.4 mg/100 ml juice). In similar research, Sharma *et al.* (2002) also reported variation in ascorbic acid in Kinnow fruits budded on 'Pectinifera'.

The maximum percentage of fruit juice was obtained on 'Carrizo' and 'Rough Lemon' (52.5% and 50.2%), followed by 'Kuharske' (49.1%) (Table 3). However, a significantly lower mean percentage of juice was obtained on 'Troyer' (47.1 %). Al-Jaleel *et al.* (2005) reported that Allen Eureka fruits grown on 'Cleopatra' and 'Amblycarpa' rootstocks had the highest juice content, while those grown on Sour Orange and Rough Lemon rootstocks had the lowest fruit juice.

The total seed number did not vary significantly on different rootstocks (Table 4). The mean total seed number per rootstock was recorded maximum on Rich 16-6 (21.9). However, the minimum mean was recorded on 'Troyer' (19.0). The maximum mean seed length (8.11 mm) and width (4.3 mm) were recorded on 'Troyer'. The significantly lower mean seed length and width was recorded on 'Rough Lemon' (6.65 mm) and 'Swingle' (4.09 mm), respectively.

The data as presented in Fig 1A revealed that rootstock altered the epicarp lightness significantly. Fruits produced on Troyer (56.4) had maximum epicarp lightness, followed by 'Rough Lemon', 'Rich 16-6',

Table 3. Effect of different rootstocks on fruit chemical characteristics of Kinnow mandarin

Root stock	TSS (°Brix)	Acidity (%)	TSS/acid ratio	Ascorbic acid (mg/100 ml Juice)	Fruit juice (%)
Kuharske	9.0b*	1.04a	8.65c	25.44c	49.1a
Rich 16-6	9.2b	0.92b	10.0b	29.88b	48.5b
Swingle	9.4b	1.06a	8.86c	26.31c	48.6b
Troyer	9.0b	0.92b	9.78b	24.4d	47.1c
Carrizo	10.1a	0.78c	12.94a	30.25a	52.5a
Rough Lemon	9.6a	0.81c	11.85a	31.10a	50.2a
CD (*p=0.05*)	1.01	0.10	1.11	3.2	2.41

*Within a column means followed by different alphabets differ significantly

Table 4. Effect of different rootstocks on seed characteristics of Kinnow mandarin

Root stock	Total no. of seed (no/fruit)	Seed length (mm)	Seed width (mm)	Seed weight of 20 seed (g)
Kuharske	21.8a*	7.59ab	4.22a	2.3a
Rich 16-6	21.9a	7.37bc	4.28a	2.1a
Swingle	20.1a	7.84ab	4.09a	1.99a
Troyer	19.0a	8.11a	4.3a	2.1a
Carrizo	21.4a	7.59ab	4.22a	2.0a
Rough Lemon	20.9a	6.65c	4.23a	2.3a
CD (*p=0.05*)	NS	0.72	NS	NS

*Within a column means followed by different alphabets differ significantly

'Carrizo', and 'Kuharske' with epicarp lightness of 54.8, 54.1, 53.2, and 46, respectively. Data presented in Fig. 1A clearly shows that rootstocks had a major impact on epicarp redness and greenness. The maximum mean epicarp redness and greenness was recorded on 'Kuharske' (27.9), followed by 'Swingle' (27.7), 'Troyer' (24.7). The maximum mean epicarp blueness and yellowness were recorded on Troyer (52.9), followed by 'Rough Lemon', 'Rich 16-6', and 'Carrizo' with epicarp blueness and yellowness of 48.5, 48.4, and 47.3, respectively. The mean value of CCI (Epicarp) of different rootstock ranged from 8.2 to 24.7 (Fig. 1D). The data show that the mean value of CCI (Epicarp) was maximum (24.7) in 'Swingle', which was at par with 'Kuharske' (17.8).

The pulp lightness was not significantly affected by any of the rootstocks (Fig 1B). The maximum mean value of pulp lightness was recorded on 'Rich 16-6' (35.7), and the minimum pulp lightness was absorbed on 'Kuharske' (31.9). The mean pulp redness and greenness was maximum on 'Troyer' (7.9), followed by 'Kuharske', 'Rich 16-6', and 'Carrizo' with pulp redness and greenness of 6.6, 6.3, and 5.2. The rootstocks did not affect the pulp blueness or yellowness. However, the mean value of pulp CCI of different rootstock ranged from 5.7 to 11.3 (Fig.1D). The data show that the mean value of pulp CCI was maximum (11.3) in Troyer, which

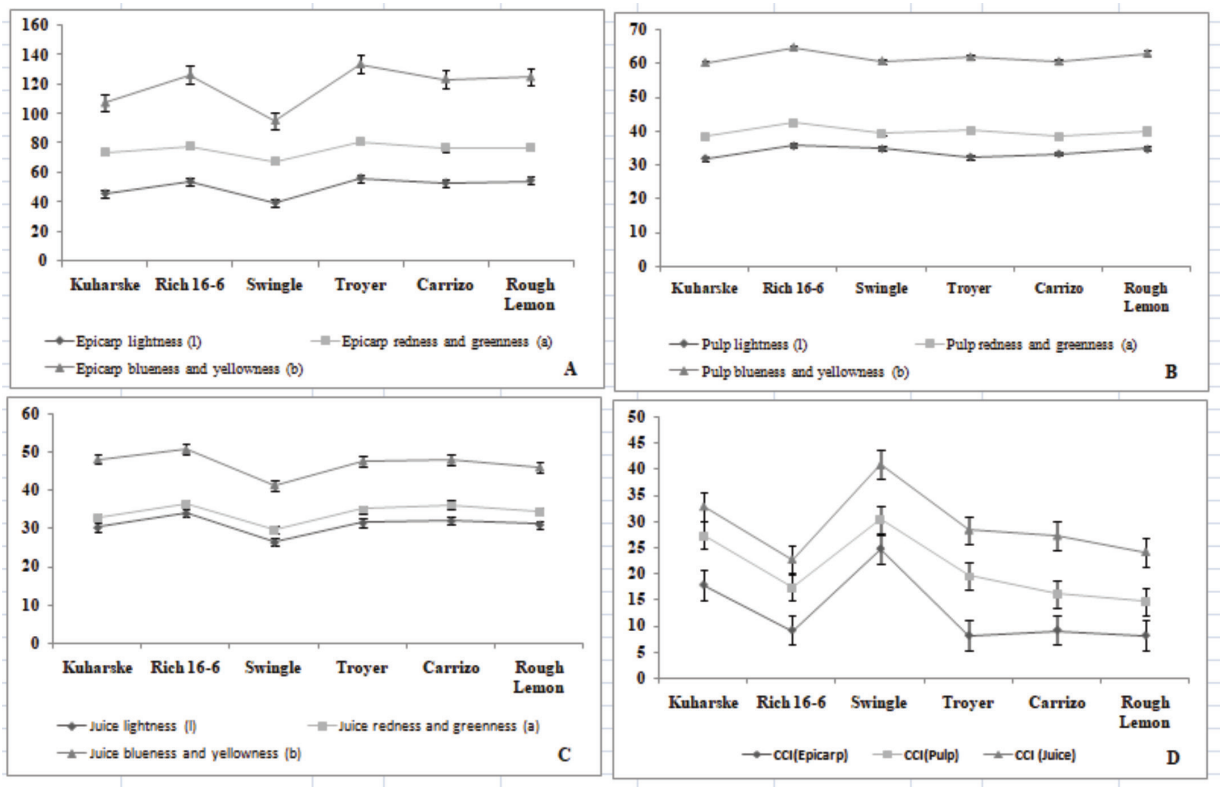

Fig. 1. Effect of different rootstocks on (A) fruit epicarp, (B) pulp, (C) juice colour and (D) CCI index of Kinnow mandarin

was statistically at par with 'Kuharske' (9.5), and it was significantly higher than all other rootstocks.

The maximum mean value of juice lightness was recorded on 'Rich 16-6' (33.9), followed by 'Carrizo' (32.0), 'Troyer' (31.5), and 'Rough Lemon' (31.0) (Fig 1C). The rootstocks had an impact on juice redness and greenness as shown in Figure 1C. The mean juice redness and greenness was the maximum on Carrizo (4.2). The mean value of juice blueness and yellowness was maximum on 'Kuharske' (15.3), followed by 'Rich 16-6' and 'Troyer 'with juice blueness and yellowness of 14.3 and 12.6. The maximum mean value of juice CCI of different rootstocks on Kinnow mandarin ranged from 5.2 to 11.1 (Fig.1D). 'Carrizo' had the highest mean value of juice CCI (11.1), which was statistically comparable to 'Swingle' (10.4) and Rough Lemon (9.4) whereas 'Rich 16-6' had the lowest juice CCI (5.2).

The results showed significant variation in the value of CCI of fruit epicarp, pulp, and juice among different rootstocks. The high positive value of CCI indicates the red-orange colour of the fruit epicarp. 'Swingle' and 'Kuharske' were highly promising rootstocks in terms of the red-orange colour of fruit epicarp, whereas 'Troyer' and 'Kuharske' had the higher red-orange colour of pulp. 'Carrizo' and 'Swingle' had the higher red-orange colour of juice. However, fruits from 'Troyer' and 'Rough Lemon' have low CCI values, which indicate a less bright orange colour of fruit epicarp. Fruit colour trait is a highly preferred trait in mandarin which is controlled by many physicochemical mechanisms (Sinha *et al.,* 2012). Besides plant nutrition, agronomic practices, biotic and abiotic stresses, and the rootstocks are the significant factors influencing fruit colour in citrus (Ladanyia, 2010). Chlorophyll (green), carotenoids (yellow, orange, and red deep orange), anthocyanins (red), and lycopene (red or pink) are the primary colour pigments responsible for colour development in citrus fruits. During the colour break stage in October under sub-tropical conditions, the fruit attains lemon-yellow colour due to the degradation of chlorophyll present in the epicarp and synthesis of carotenoids (Artes *et al.,* 2002). The attractive orange colour indicates the ripeness of fruits and stimulates the perception of freshness in the consumers' minds.

The results indicated the feasibility of using hunter lab to assess the influence of different rootstocks on fruit colour in citrus. The rootstocks under study belong to different geographical origins, and they have different maturity times under sub-tropical conditions, thus imparting other chromaticity scores to the Kinnow fruits. The high positive value of CCI indicates the red-orange colour of the fruit epicarp, pulp, and juice. Kinnow fruits from 'Swingle', 'Kuharske', and 'Carrizo' rootstocks had significantly higher values which clearly stated the better colour development. Similarly, the maturity of mandarin germplasm was assessed by Singh *et al.* (2017) based on fruit chromaticity scores. They reported that Kinnow is a distinct mandarin variety with higher chromaticity scores in CCI under sub-tropics.

The study indicated that Kinnow budded on different rootstocks responded differently to six rootstocks tested regarding plant morphological performance, fruit yield and fruit quality. The study concluded that the highest plant canopy volume, fruit weight, fruit yield, and TSS/acid ratio were recorded on 'Carrizo' rootstock, followed by 'Rough Lemon'. However, ascorbic acid and juice content were higher in Kinnow fruits budded on 'Rough lemon' followed by 'Carrizo'. Furthermore, Kinnow fruits from 'Carrizo', 'Swingle', and 'Kuharske' rootstocks had significantly higher CCI values, indicating better colour development on these rootstocks. 'Swingle' rootstock showed the lowest yield but the highest yield efficiency due to its dwarf nature.

Authors' contribution

Conceptualization of research work and designing of experiments (JM and GS). Execution of field/lab experiments and data collection (JM). Analysis of data and interpretation (HSR and GS), Preparation of manuscript (JM, GS, HSR, MG).

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