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Long-term performance of grapefruit cultivars on different rootstocks

R. M. Sharma[*], A. K. Dubey, O. P. Awasthi, V. K. Sharma[1] and Amrender Kumar[2]

Division of Fruits & Horticultural Technology, ICAR-Indian Agricultural Research Institute,
New Delhi-110012, Delhi, India.

ABSTRACT

The present study was conducted to standardize the rootstock(s) for grapefruit cvs. Marsh Seedless and Redblush, suitable to grow commercially in northern India, budded on eight rootstocks. The sour orange and RLC-4 proved to be the vigorous rootstocks for Marsh Seedless (220.32 m3) and Redblush (175.65 m3) cultivars. The trees of Marsh Seedless were dwarf (51.23 – 52.27m3) on Attani-1 and Attani-2 rootstocks, while statistically similar growth of Redblush (46.52 m3) was observed on Jatti khatti rootstock. Jatti khatti and Billikhichli were good nutrient accumulators (P, K, and Mg) for Redblush, Jatti Khati and RLC-4 for Marsh Seedless (N, P, and Zn). Billikhichli and sour orange proved to be the sodium excluder rootstocks for both varieties. RLC-4 and Rough lemon proved to be the most productive rootstocks for Redblush and Marsh Seedless, respectively. It was followed by Troyer citrange for both the cultivars. These rootstocks also yielded the juiciest fruits in their respective cultivars. Attani-1 and Troyer citrange produced fruits with low acid content in the tested cultivars of grapefruit.

Keywords: *Citrus paradisi* Macf., Fruit quality, Nutrients, Tree vigour, Yield efficiency.

INTRODUCTION

Grapefruit (*Citrus paradisi* Macf.), which originated as an accidental cross between sweet orange and pummelo, is a leading citrus fruit for fresh juice production with diverse colours (creamy white, pink, and red) of segmented flesh. Grapefruit contains a number of nutrients beneficial to human health. Grapefruit cultivars have higher phenolics and antioxidant capacities than pummelos. Hence, they are a good sources of natural phytochemical antioxidants. There is a growing awareness about the medicinal value of grapefruit juice. Two grapefruit cultivars, Marsh Seedless, and Redblush are in great demand in India among consumers, being seedless citrus fruits. They are available in the supermarkets of metropolitan cities and are also being marketed online by some reputed companies.

A variety of rootstocks have been developed for citrus fruits, however, their impact on scion varieties is location and fruit specific. The increasing wealth of data highlight the strong influence of rootstock on the traits of economic relevance including tree vigour (Bowman and Joubert, 2), fruit yield, maturity, and fruit quality of citrus (Carvalho *et al*., 4). Besides, the rootstocks had a strong impact on the accumulation of individual nutrient in the leaves of scion varieties. Variation in the accumulation of foliar nutrients in the leaves of local lemon was noted, when budded on *C. swingle* (N and P) and sour orange (K and Fe) rootstocks (Al-Zuhari *et al*., 1).

The seedless or very low-seeded fruits with high juice content and precocious maturity (last week of October) of Marsh Seedless and Redblush grapefruits in north Indian plains have made it a highly preferred citrus fruit for fresh juice consumption. Despite of immense potential for the area expansion under grapefruit cultivation, no conclusive study has been made on standardization of rootstock for these cultivars. Keeping in view commercializing the seedless grapefruit, the present study was planned for a conclusive recommendation of the best rootstock for grapefruit cultivation in the northern part of India.

MATERIALS AND METHODS

The present studies were made in the Citrus Research Block of Division of Fruits & Horticultural Technology, ICAR-Indian Agricultural Research Institute, New Delhi, India. The soil pH was 7.4 having an electrical conductivity [$EC_{(1:2)}$ (w/v) soil/water] of 0.75 dS m^{-1}, the organic carbon content of 0.48% (w/w), a soil N concentration of 240.23 kg ha^{-1}, a soil P_2O_5 concentration of 58.65 kg ha^{-1}, and a soil K_2O concentration of 555.92 kg ha^{-1}.Two grapefruit cultivars (Marsh Seedless and Redblush), each budded on eight different rootstocks *viz*., rough lemon (*C. jambhiri* Lush), Jatti Khatti (*C. jambhiri* Lush), Attani-1 (*C. rugulosa* Hort. ex Tanaka Accession No. IC 285452), Attani-2 (*C. rugulosa* Hort. ex Tanaka Accession No. IC 285453), Billikhichli (*C. reshni* Hort.

*Corresponding author: rmsharma345@gmail.com
[1]Division of Soil Science & Agricultural Chemistry, ICAR-IARI, New Delhi-110012, Delhi, India
[2]AKMU, ICAR-IARI, New Delhi-110012, Delhi, India

ex Tanaka), sour orange (*C. aurantium* L.), RLC-4 (*C. jambhiri* Lush Accession No. IC 274693) and Troyer citrange (*C. sinensis* (L.) Osbeck × *Poncirus trifoliata* (L.) Raf) were planted in 2010 at a spacing of 4.5 m × 4.5 m in a factorial randomised complete-block design with five replications. The data on tree growth characteristics and leaf nutrient status were recorded from 2015 onwards, however, the data on fruit yield and quality parameters were recorded from 2016 onwards, when both the scion cultivars attained the tree architecture to produce the yield uniformly on all the rootstocks. Each experimental tree was supplied with 40 kg of farmyard manure in January, and 400 g N, 200 g P_2O_5, and 400 g K_2O, applied during late March (after fruit set).

Canopy volume (CV) was measured in January, 2020 (after fruit harvesting) as per the equation suggested by Westwood (18). Four months old 30 leaves were randomly collected from each tree per replication from all directions, washed with tape water followed by double distilled water. The leaf samples were then dried in an oven (at 70° ± 1°C) for 48 h. The leaf nitrogen (N) content was determined as per the method of Bremner (3). The leaf phosphorus was estimated by vando-molybdophosphoric yellow colour method (Jackson, 8). Total Na^+ and K^+ contents in leaves were estimated according to Jackson (9) using a microprocessor based flame photometer (Flame Photometer-128, Systronics, New Delhi, India). However, Mg^{2+}, Mn^{2+}, Zn^{2+}, and Fe^{2+} contents were determined by atomic absorption spectrophotometer (Model- GBC, Avanta, Scientific Equipment Pty Ltd, Victoria, Australia). Fruit yield was recorded at commercial maturity by harvesting the whole quantity of fruits. The yield efficiency was calculated by dividing the total yield per tree with CV. The juice of freshly harvested fruits was extracted, and expressed as per cent (w/v basis). For quality analysis, 20 fruits were sampled from each replication. Juice was filtered through filter paper, thereafter, juice samples were studied to determine the titratable acidity (% of citric acid) using N/10 NaOH and phenolphthalein as indicator, and total soluble solids (TSS) using digital refractrometer (ATAGO, PAL-3, Japan).

The data were analysed statistically using two-way analysis of variance, followed by Tukey's Honest Significant Difference (HSD) using SAS Software Version 9.3 (SAS Institute, Cary, NC, USA). $P \leq 0.05$ were considered significant.

RESULTS AND DISCUSSION

The tree vigour of both the grapefruit cultivars (C) in terms of canopy volume (CV) was significantly influenced on the different rootstocks (R) (Table 1). Irrespective of the rootstocks, the grapefruit cultivars, Marsh Seedless and Redblush did not differ significantly in respect of CV. However, the sour orange rootstock proved to be the most vigorous in terms of canopy volume (189.99 m^3). Collectively (C × R), sour orange and RLC-4 proved to be the vigorous rootstocks for Marsh Seedless (220.32 m^3) and Redblush (175.65 m^3) cultivars, respectively. The trees of Marsh Seedless had the lowest CV (51.23 m^3) on Attani-2 rootstock which did not differ statistically with the CV of March Seedless on Attani-1 and Redblush on Jatti Khaiti (46.52 m^3).The tree vigour of Kagzi Kalan lemon trees was found to be regulated by rootstocks being higher on rough lemon and RLC-4 rootstocks than others (Dubey and Sharma, 6). Although, the dwarf graft combinations is economically viable for an orange cultivar that guarantees high income due to more number of trees per unit area (Gullo *et al.*,7), however, in the present study, poor nutrients absorption (Table 2) might be the possible reason of low tree vigour on Attani collections.

The levels of foliar nutrients (N, P, K, Mn, Cu, Zn, Fe and Na) in both the cultivars were significantly altered by citrus rootstocks (Table 2 and Figures 2-3). Irrespective of the rootstocks, significantly higher uptake of leaf P (0.18%), Cu (5.26ppm), Zn (27.40 ppm) and Fe (152.84 ppm) was recorded in Redblush cultivar than Marsh Seedless, while

Table 1. Rootstock induced changes in the canopy volume of grapefruit cultivars (2020).

Cultivar (C)	Rootstock (R)								Mean
	Rough lemon	Attani-1	Attani-2	Jattikhatti	Billikichli	Sour orange	RLC-4	Troyer citrange	
	Canopy volume (m^3)								
Marsh Seedless	103.30^f	52.27^j	51.23^{kj}	80.52^h	156.32^c	220.32^a	135.42^d	106.40^f	113.22^a
Redblush	134.02^d	94.01^g	93.64^g	46.52^k	120.32^e	159.63^c	175.65^b	67.85^i	111.45^a
Mean	118.66^d	73.14^f	72.43^f	63.52^g	138.32^c	189.98^a	155.57^b	87.12^e	

Mean values in each column and for each grapefruit cultivar, rootstock, or cultivar-rootstock combination followed by different lower-case letters were significantly different at $P \leq 0.05$ by Tukey's HSD test.

Table 2. Effect of cultivar and rootstock on leaf nutrient status of grapefruit (pooled mean for five years).

Rootstock/Cultivar	N (%)	P (%)	K (%)	Mg (%)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Na (%)
					Cultivar (C)				
Marsh Seedless	2.98^{a}	0.17^{b}	1.20^{a}	0.48^{b}	41.09^{a}	4.50^{b}	25.73^{b}	139.91^{b}	0.15^{a}
Redblush	2.99^{a}	0.18^{a}	1.20^{a}	0.49^{a}	41.48^{a}	5.26^{a}	27.40^{a}	152.84^{a}	0.12^{b}
					Rootstock (R)				
Rough lemon	3.03^{d}	0.16^{c}	0.96^{g}	0.47^{cd}	69.89^{a}	4.44^{de}	27.34^{b}	157.85^{b}	0.21^{a}
Attani-1	1.77^{e}	0.16^{c}	1.01^{f}	0.26^{e}	36.69^{e}	3.71^{e}	25.37^{c}	145.75^{c}	0.14^{c}
Attani-2	2.99^{d}	0.18^{b}	1.21^{d}	0.46^{d}	42.28^{c}	5.49^{b}	30.43^{a}	196.11^{a}	0.11^{e}
Jattikhatti	3.43^{a}	0.19^{a}	1.35^{b}	0.57^{a}	40.65^{d}	5.74^{a}	27.87^{b}	141.68^{d}	0.14^{c}
Billikichli	3.20^{c}	0.19^{ba}	1.23^{dc}	0.51^{a}	26.76^{h}	5.23^{c}	26.12^{c}	126.54^{e}	0.10^{e}
Sour orange	3.23^{cb}	0.18^{ba}	1.26^{c}	0.57^{a}	29.23^{g}	4.43^{d}	25.25^{c}	120.86^{f}	0.07^{f}
RLC-4	3.29^{b}	0.18^{ba}	1.47^{a}	0.49^{cb}	51.16^{b}	4.54^{d}	30.07^{a}	156.05^{b}	0.16^{b}
Troyer Citrange	2.95^{d}	0.17^{b}	1.13^{e}	0.51^{b}	33.64^{f}	5.47^{b}	20.06^{d}	126.16^{e}	0.12^{d}

Mean values in each column and for each grapefruit cultivar and rootstock by different lower-case letters were significantly different at $P \leq 0.05$ by Tukey's HSD test.

significantly higher accumulation of Na (0.15%) was recorded in the leaves of Marsh Seedless than the Redblush cultivars. Both the cultivars were found to be statistically similar in respect of N, K and Mn contents in leaves. Of the various rootstocks tested, Jatti Khatti tended to show higher contents of N (3.43%), P (0.19%), Mg (0.57%) and Cu (5.74ppm) over the other rootstocks, however, it was statistically similar with Billikhichli, sour orange and RLC-4 for P and with Billikhichli and sour orange for Mg. RLC-4 resulted in highest uptake of K (1.47%) and Zn (30.07ppm) over other rootstocks. The highest contents of Mn (69.89ppm) and Na (0.21%) were noticed with rough lemon, while highest leaf Fe (196.11ppm) was contributed by Attani-2 rootstock. The lowest uptake of majority of the nutrients was recorded in Attani-1 (Table 2).

The interaction between the cultivar (C) and rootstock (R) (Figure 1A to D) shows the highest N accumulation on the rootstock-scion combination of Jatti Khatti with Marsh Seedless (3.38%) and Redblush (3.47%) which had statistical similarity with Marsh Seedless on RLC-4. Jatti Khatti, RLC-4 and Troyer citrange proved to be equally good in improving the leaf P content in Marsh Seedless (0.18%), while it was highest in Redblush (0.20%), grown on JattiKhatti or Billikhichli rootstock. The highest K (1.53%) content in Marsh Seedless was recorded on RLC-4 rootstock, however, in Redblush the similar results were noticed on Jatti Khatti and Billikhichli (1.34-1.36%) rootstocks. Billikhichli and sour orange rootstocks proved superior for the leaf Mg level (0.54-0.55%) in Marsh Seedless, while Jatti Khatti and Billlikhichli proved equally effective in respect of Mg accumulation (0.63% in each) in the leaves of Redblush cultivar. By and large, Attani-1 proved to be a poor nutrient accumulator in both the cultivars studied (Fig. 1A-D).

The interaction of rootstock and cultivar also exerted the significant influence on leaf micro-nutrients (Mn, Cu, Zn and Fe) and sodium (Na) contents (Fig. 2A to E). The highest Mn content in Marsh Seedless (57.32ppm) and Redblush (82.46ppm) was recorded on rough lemon, however, it was statistically similar with the Mn level in Marsh Seedless on Troyer citrange. The combination of Marsh Seedless and Attani-2 and Troyer citrange was statistically similar in improving the Cu content (5.46-5.68 ppm) in leaves, whereas the statistically similar Cu levels were recorded in Redblush on Jatti khatti rootstock. The leaves of Marsh Seedless had the higher content of Zn, when budded on Attani-2, Jatti khatti or RLC-4 (28.02-28.89 ppm) rootstocks without having significant difference. The higher Zn levels in Redblush were recorded on Attani-2 or RLC-4 (32.82-32.05ppm) rootstocks. RLC-4 and Attani-2 also proved to be the good Fe accumulators for Marsh Seedless (168.11ppm) and Redblush (245.84ppm) cultivars, respectively. Billikhichli and sour orange were noticed to be good Na excluder rootstocks for both the grapefruit cultivars.

The performance of a cultivar is largely dependent on the rootstock-scion interactions. Rootstocks can differ markedly in their ability to uptake and use nutrients from the soil (Bowman and Joubert, 2). The variations in N, P, K, Fe, Zn, Mn, Na and Cu level of lime grafted on different rootstocks have been earlier reported by Khankahdani *et al*.

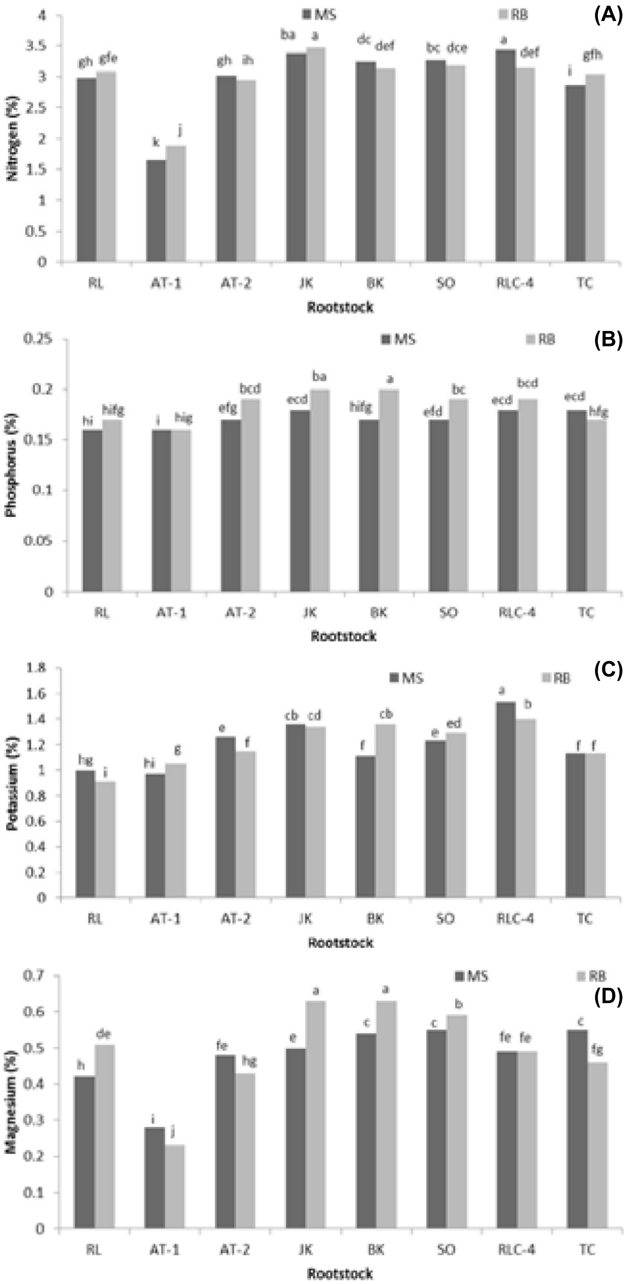

Fig. 1 (A-D). Rootstock induced changes in the leaf macro-nutrients in grapefruit cvs. Marsh Seedless (MS) and Redblush (RB) (Pooled mean of five years 2015-2019)

Rootstocks: RL-Rough lemon; AT-1- Attani-1; AT-2- Attani-2; JK-JattiKhatti; BK-Billikichli; SO-Sour orange; RLC-4-Rough lemon collection-4; TC-Troyer citrange

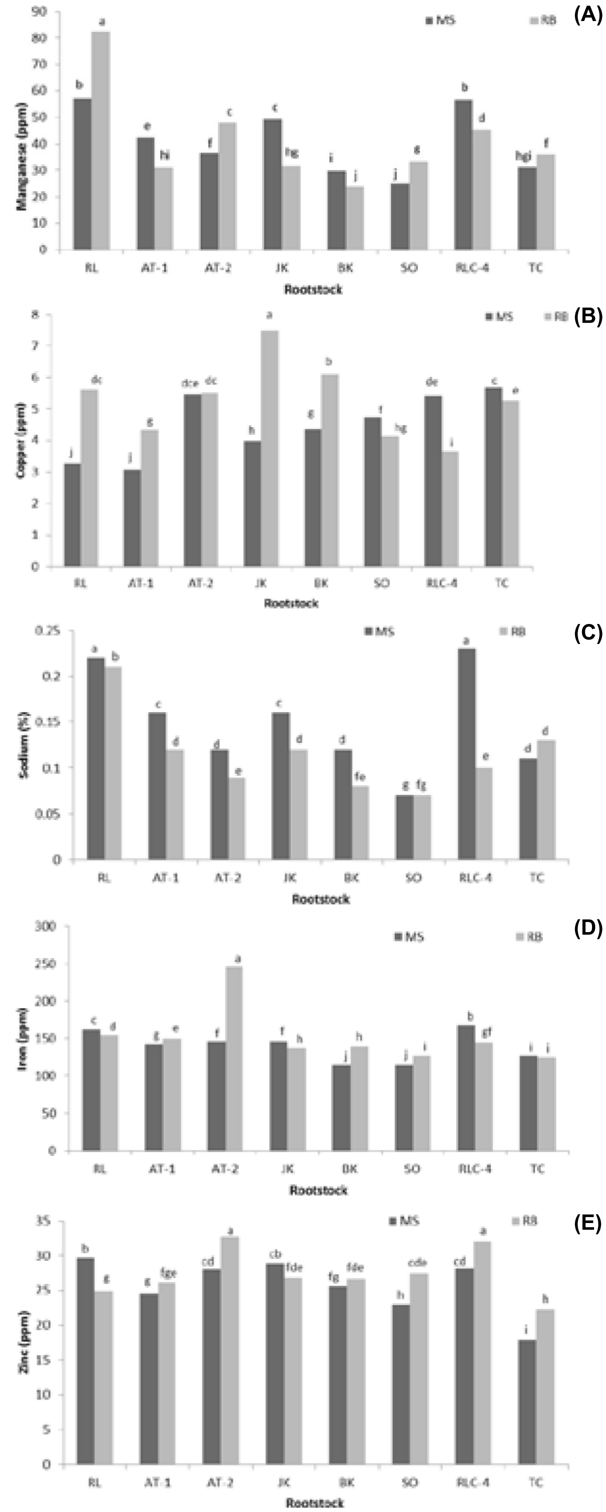

Fig. 2 (A-E). Rootstock induced changes in the leaf nutrient contents in grapefruit cv. Redblush (Pooled mean of five years 2015-2019)

Rootstocks: RL-Rough lemon; AT-1- Attani-1; AT-2- Attani-2; JK-Jatti Khatti; BK- Billikichli; SO-Sour orange; RLC-4-Rough lemon collection-4; TC-Troyer citrange

(10, 11). Uptake and transport of sufficient K and lower Na:K ratios are associated with increased cell growth, accumulation of simple carbohydrates, higher chlorophyll content, photosynthesis enhancement, and eventually increased growth and productivity (Romheld and Kirkby,14). In the present studies, the differential nutrient levels might be attributed to the inherent difference in selectivity to absorb nutrients by the rootstocks (Kumar *et al*., 12), and its utilization by the scion is governed by the genetic character of the particular scion (Sharma *et al*.,15). The variation in leaf nutrient levels of the grapefruit varieties may also be due to differences in hydraulic conductance of different rootstocks, which is positively correlated with nutrient accumulation (Cohen and Naor, 5).

The yield and fruit quality of Marsh Seedless and Redblush cultivars of grapefruit showed the significant variation on the different rootstocks (Table 3).

Table 3. Effect of rootstock on yield and fruit quality of grapefruit cvs. Marsh Seedless and Redblush (pooled mean for five years).

Rootstock/Cultivar	Yield efficiency (Kg m^{-3} CV)	Yield (Kg/tree)	Juice (%)	TSS (°B)	Titratable acidity (%)
Cultivar					
Marsh Seedless(MS)	0.31^{a}	22.33^{b}	45.44^{a}	8.04^{b}	1.02^{b}
Redblush (RB)	0.36^{a}	26.55^{a}	45.63^{a}	8.48^{a}	1.08^{a}
Rootstock					
Rough lemon	0.34^{c}	33.06^{a}	46.08^{bdc}	8.77^{ba}	0.99^{c}
Attani-1	0.48^{ba}	17.74^{f}	43.91^{ef}	7.94^{de}	0.96^{c}
Attani-2	0.33^{c}	20.31^{e}	44.49^{edf}	7.93^{de}	1.05^{b}
Jattikhatti	0.38^{bc}	16.16^{g}	45.22^{edc}	7.86^{e}	1.10^{b}
Billikichli	0.20^{d}	22.60^{d}	43.25^{f}	9.15^{a}	1.18^{a}
Sour orange	0.18^{d}	24.34^{c}	47.89^{a}	7.62^{e}	1.09^{b}
RLC-4	0.22^{d}	27.84^{b}	47.19^{ba}	8.51^{bc}	1.06^{b}
Troyer citrange	0.55^{a}	33.48^{a}	46.28^{bac}	8.30^{dc}	0.97^{c}
Cultivar × Rootstock					
Marsh Seedless (MS)					
MS on Rough lemon	0.38^{cb}	32.22^{dc}	46.38^{ebdac}	8.16^{cebd}	1.04^{fed}
MS on Attani-1	0.62^{a}	17.23^{ihj}	42.85^{gf}	7.68^{fed}	0.96^{hg}
MS on Attani-2	0.37^{cbd}	19.19^{h}	41.78^{g}	7.98^{cefd}	1.06^{fed}
MS on Jattikhatti	0.30^{ced}	15.47^{j}	45.93^{ebdc}	7.53^{f}	1.03^{feg}
MS on Billikichli	0.17^{fe}	23.19^{feg}	47.46^{bdac}	8.62^{b}	1.09^{ced}
MS on Sour orange	0.13^{f}	23.71^{fe}	48.50^{a}	7.63^{fe}	1.04^{fed}
MS on RLC-4	0.16^{fe}	17.08^{ihj}	46.36^{ebdac}	8.42^{cb}	1.00^{fhg}
MS on Troyer Citrange	0.37^{cbd}	30.56^{d}	44.29^{ef}	8.28^{cb}	0.94^{h}
Redblush (RB)					
RB on Rough lemon	0.31^{ced}	33.90^{c}	45.78^{edc}	9.37^{a}	0.94^{h}
RB on Attani-1	0.35^{cbd}	18.24^{ih}	44.97^{edf}	8.21^{cbd}	0.95^{h}
RB on Attani-2	0.28^{ced}	21.42^{g}	47.20^{bdac}	7.87^{cefd}	1.04^{fed}
RB on Jattikhatti	0.47^{b}	16.84^{ij}	44.51^{ef}	8.17^{cebd}	1.17^{b}
RB on Billikichli	0.22^{fed}	22.01^{fg}	39.05^{h}	9.68^{a}	1.28^{a}
RB on Sour orange	0.23^{fed}	24.97^{e}	47.27^{bdac}	7.61^{ef}	1.14^{cb}
RB on RLC-4	0.28^{cfed}	38.60^{a}	48.01^{bac}	8.60^{b}	1.11^{cbd}
RB on Troyer citrange	0.73^{a}	36.40^{b}	48.28^{b}	8.31^{cb}	1.00^{fhg}

Mean values in each column and for each grapefruit cultivar, rootstock, or cultivar-rootstock combination followed by different lower-case letters were significantly different at $P \leq 0.05$ by Tukey's HSD test.

Without considering the effect of roostock, Redblush grapefruit expressed the statistical superiority for yield (26.55 Kg/tree) and TSS (8.48°B) over Marsh Seedless, while the Marsh Seedless yielded sweeter fruits (1.02% acidity) than the Redblush (1.08%). Irrespective of the cultivars, highest yield efficiency (0.55 Kg m^{-3}) was contributed by Troyer citrange, which did not differ significantly with the yield efficiency on Attani-1. Troyer citrange (33.48 Kg $tree^{-1}$) and rough lemon (33.06 Kg $tree^{-1}$) did not differ statistically for the fruit yield. The combination of Marsh Seedless with Attani-1 showed the highest yield efficiency (0.62 Kg m^3 CV), while in Redblush, the highest yield efficiency (0.73 Kg m^{-3} CV) was recorded on Troyer citrange. The highest fruit yield of Marsh Seedless (32.22 Kg $tree^{-1}$) and Redblush (38.60 Kg $tree^{-1}$) was obtained on rough lemon and RLC-4 rootstocks, respectively. Troyer citrange proved to be second best productive rootstock for Redblush (36.40 Kg/tree) as well as Marsh Seedless (30.56 Kg/tree). The rootstocks Attani-1, Jatti Khatti and RLC-4 resulted in lower yields in Marsh Seedless; and Jatti Khatti and Attani-1 also led to poor yield in Redblush. The variation in fruit density of Kagzi Kalan lime has also been reported due to rootstocks (Dubey and Sharma, 6). Rough lemon and Bakraei rootstocks have been found to be the best rootstocks for lime, while, sour orange was the most unsuitable rootstock (Tavakoli, 16).

Sour orange, RLC-4 and Troyer citrange produced the juiciest fruits (46.28-47.89 %) of grapefruit. The highest juice TSS content was noticed on Billikhichli (9.15°B) which did not differ significantly with the juice TSS on rough lemon. The fruits of grapefruit cultivars with lower acid content were obtained on rough lemon, Attani-1 and Troyer citrange (0.96-0.99%) rootstocks. The highest acidity (1.18%) was recorded in the grapefruit fruits grown on the Billikhichli rootstock. The juice content of Marsh Seedless was significantly improved by rough lemon, Billikhichli, sour orange and RLC-4 (46.36-48.50%) rootstocks. In Redblush, better juice content was observed on Attani-2, sour orange and RLC-4 (47.20-48.01%). The highest juice TSS in Marsh Seedless (8.62˚B) was registered on Billikhichli rootstock, which did not differ statistically with the TSS levels on rough lemon and RLC-4 rootstocks. The rootstock-scion combination of Redblushon rough lemon (9.37˚B) and Billikhichli (9.68˚B) proved to be better in terms of very high TSS content of fruit juice (9.37-9.68˚B) than the other combinations tested. The Attani-1, RLC-4 and Troyer citrange rootstocks resulted in very low acid levels (0.94-1.00%) in Marsh Seedless, whereas rough lemon, Attani-1 and Troyer citrange led to the very low acid content in Redblush. The rootstock can influence fruit quality parameters and nutritional juice parameters (Magwaza *et al.*,13; Sharma *et al.*,15). Rootstock-scion combination is a reciprocal system, crucial to fruit quality and juice and sap composition, with possible impact on tree physiology. The present studies suggested a reciprocal relationship between the scion and roots in a grafted tree, whereby a mutual alteration/acclimation process in the metabolism is developing in the forced connection between two different genotypes. Furthermore, characteristics of either a scion or a rootstock cannot be determined for themselves, but rather only in interaction with each scion/ rootstock. Accordingly, choosing a rootstock-scion combination should first take into consideration the required characteristics of either the scion or the rootstock, followed by a careful choice of its compatible partner (Tietel *et al.*,17).

AUTHORS' CONTRIBUTION

Conceptualization of research (R. M. Sharma), Designing (A. K. Dubey) and Execution of experiment (R. M. Sharma and V. K. Sharma), Contribution in data analysis (Amrender Kumar) and preparation of manuscript (R. M. Sharma and O. P. Awasthi).

DECLARATION

The authors declare no conflict of interest.

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