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Studies on growth, rooting and budding performance of citrus rootstock seedlings

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Abstract

A study was conducted at Punjab Agricultural University, Fruit Research Station, Jallowal-Lesriwal, Jalandhar to evaluate nursery performance of different exotic rootstocks and their budding compatibility with Kinnow mandarin. The seeds of exotic rootstocks: Swingle citrumelo, Rich 16-6, Rubidoux trifoliate (RTF), US-852, Benton citrange, Troyer citrange, Kuharsuke citrange, C-35 citrange, X-639, Carrizo citrange, Gou Tou, Shin Chu Sha, Rangpur Lime, Volkameriana lemon and Rough lemon were sown in protrays and later transplanted in poly-bags under protected conditions. The results of the experiment revealed that maximum plant height and stem thickness were recorded in C-35 citrange and Swingle citrumelo, respectively. The number of leaves/plant was highest in X-639. Volkameriana lemon and Benton citrange had the longest and thickest roots at the buddable stage, respectively. Fresh and dry root weight was maximum in Rangpur lime rootstock. Kinnow mandarin (*Citrus reticulata* Blanco) was budded on all the rootstocks under study and the highest budding success was recorded in Rough lemon, followed by Volkameriana lemon, Rangpur lime and Kuharsuke citrange. It was concluded that Volkameriana lemon, Kuharsuke citrange and Rangpur lime can also be explored as potential rootstocks along with Rough lemon for raising the nursery of Kinnow mandarin under protected conditions in Punjab. However, their long-term effects on fruit yield and quality, as well as stionic compatibility, should be carefully considered before making any commercial recommendations.

Key words: Citrus, rootstock, nursery performance, budding success

Introduction

Citrus, being intensively cultivated from tropical to temperate regions, is among the most important fruit crops having significant economic value worldwide (Le *et al.,* 2020). The worth of dependable rootstock needs no highlighting for the citrus industry as it is an important component of a healthy and productive plant, influencing the fruit yield, fruit quality, tree size and tolerance to diseases (Bowman and Joubert, 2020). Rootstocks have contributed and will contribute in the future largely to success and failures in this area. Therefore, considerable efforts have been made in the past for research and evaluation of rootstocks regarding their adaption in variable climatic circumstances under diversified regions. Rootstocks provide growers with functional tools to manipulate the productivity and growth of fruit plants. The complex interrelationship between the rooting area and the plant's vegetative growth aids in achieving effects on fruit quality parameters such as precocity, tree vigor, fruit yield, and maturity (Ahmed *et al.*, 2006). Many scientists have recognized the strong effects of rootstock on the quality of fruit, tree growth and yield. The rootstock along with supporting the tree in the soil and altering the tree canopy, also helps in the uptake of moisture and nutrition from the soil, adaption of scion to specific soil conditions, helping assimilation of carbohydrates and bringing tolerance for diseases.

The requirement of dependable rootstocks in the citrus industry was first recognized in the 1830s with the advent of *Phytophthora* root rot, leading to great devastation of own-rooted sweet orange (*Citrus sinensis*) plantations around the world. This led to widespread use of rootstock, popularizing sour orange (*Citrus aurantium*) (Ampatzidis *et al.,* 2019). A model citrus rootstock must be tolerant to biotic and abiotic stresses and should have high compatibility with major scion varieties of the area. It is critical to select appropriate stionic combinations (Arce and Rivera, 2018) for the region by evaluating various rootstock types, as scion cultivar performance is highly dependent on them. It is not advisable to adopt rootstock recommended in the world without their evaluation under local conditions due to the region's specific variations in cultural practices and climatic conditions. Besides having tolerance against prevalent environmental conditions, a successful rootstock should also have good nursery characteristics as the commercial acceptance of a rootstock is based on both its field and nursery performance (Castle and Youtsey, 1977). In fact, the primary criterion for rootstock screening is the nursery evaluation and presence of quality nursery traits. To meet the local demand for a specific stionic combination, a desirable rootstock must have budding compatibility with the scion cultivar.

In the case of the citrus industry of Punjab, the prime concerns are the quality of fruits, productive age of the orchard, *Phytophthora* and fruit drop. The use of suitable/tolerant rootstock is the simplest way to overcome losses incurred from these problems. Rough lemon has been the most widely used citrus rootstock in the state, in spite of susceptibility to *Phytophthora* and restricted productive life of orchards (Singh *et al.,* 2019). Significant reactions shown by this rootstock towards biotic and abiotic stresses, especially *Phytophthora,* invite high level of hygienic

conditions during nursery production. However, provision of the required infrastructure and other resources for maintaining disease free conditions is not possible in all the nurseries in the current scenario. Further, this rootstock should only be used for plantations where citrus has not been planted before. These drawbacks of Rough Lemon can be the limiting factors in hampering the growth of the citrus industry in the region. Considering the significant roles played by the rootstocks and drawbacks of the currently used stock in the state, the need for dependable new rootstock is of chief concern.

Hence, keeping in view the requirement for new dependable rootstock for the region's most dominant citrus variety, Kinnow, present study was designed to investigate a broad group of stocks with objectives to evaluate nursery performance of different exotic rootstocks and their budding compatibility with Kinnow mandarin.

Material and methods

The present study was conducted at Fruit Research Station, Jallowal-Lesriwal, Jalandhar, India during 2016-17. The station represents typical sub-tropical climatic conditions (Latitude, 31° 29' 38" N and Longitude, 75° 37' 40" E) and falls under the central fruit zone of Punjab province. The daily mean maximum temperature calculated at this place is 40.75°C whereas the mean minimum temperature is 5.15°C with annual average rainfall of 701 mm (Kahlon *et al.,* 2010). Seedlings of fifteen exotic rootstock types were raised under protected conditions.

Rootstocks: In this study, nursery performance of different exotic rootstocks was tested. Among the fifteen exotic rootstocks was Rough Lemon, which is commercially used for the most dominant citrus variety, Kinnow mandarin, under Punjab conditions. The nursery performance of Swingle citrumelo, Rich 16-6, Rubidoux trifoliate, US-852, Benton citrange, Troyer citrange, Kuharsuke citrange, C-35 citrange, X-639, Carrizo citrange, Gou Tou, Shin Chu Sha, Rangpur Lime, Volkameriana and Rough Lemon was studied.

The Experiment was laid out as Completely Randomized Block Design & Randomized Block Design (Factorial) and replicated thrice. All rootstock seeds were extracted from healthy fruits collected from a single-tree source. These seeds were planted in propagation displays filled with sterilized farm soil + cocopeat (1:1) and Ridomil MZ 72 WP. Twenty cell protrays with dimensions of 18.5 cm length, 14.7 cm breadth, 12.0 cm depth, and 3.3 cm cell diameter were used for seed sowing. Seedlings were transplanted into poly-bags in July under screen house conditions. Data on growth parameters, such as plant height, stem thickness, and average number of leaves, were collected at 30-day intervals. Root length, root thickness, fresh weight, and dry weight were all measured at the buddable stage.

Before carrying out the budding operation, ten plants in each replication were sampled and carefully uprooted. After thorough washing in running tap water, they were put in polythene bags and brought to the laboratory immediately. To remove the dust and other foreign particles, plants were subjected to washing in detergent solution and 0.1 N HCL. The samples were oven dried at 70 °C to constant weight. The dry weight of samples was recorded and the average was calculated.

Kinnow mandarin (*Citrus reticulata* Blanco) was budded on different rootstocks during February 2017 after the attainment of buddable stem thickness. Data regarding budding success was recorded during February, March and April 2017. On all exotic rootstock seedlings, 'T' budding was done at the height of 20 cm above ground level using the bud wood from the virus free foundation block of kinnow. On the basis of sprouted buds, the percent of budding success was determined after 45 days.

Results and discussion

Plant height: Periodic increment in plant height was observed in all the rootstocks after seed sowing. The average maximum (29.3 cm) plant height was noted in C-35 citrange and it was significantly higher in comparison to other rootstocks. Carrizo citrange, X-639, Swingle citrumelo, Troyer citrange, Kuharsuke citrange, Benton citrange and Rangpur lime attained a mean height level of more than 20 cm.

After 60 DAS, the maximum plant height was 6.50 cm in Kuharsuke citrange, followed by Swingle citrumelo (6.10 cm)

Table 1. Plant height at periodic intervals in exotic citrus rootstocks under protected conditions

Rootstock	Plant height (cm)												Mean
	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	210 DAS	240 DAS	270 DAS	300 DAS	330 DAS	360 DAS	390 DAS	
Rich 16-6	4.20	6.23	7.47	7.90	9.40	15.20	18.87	19.33	19.66	19.86	19.90	21.62	14.14
Rubidoux trifoliate	3.60	4.07	4.56	6.10	10.10	15.80	19.96	22.05	22.70	23.13	23.40	26.02	15.12
Benton citrange	5.30	7.77	9.66	11.16	14.50	22.90	27.46	29.20	29.92	30.24	31.70	37.25	21.42
Troyer citrange	3.80	5.84	7.49	8.80	13.96	23.36	28.49	31.19	32.20	32.96	38.70	48.33	22.93
Kuharsuke citrange	6.50	8.60	9.75	10.40	12.80	21.20	25.38	28.38	29.10	29.98	34.70	41.66	21.54
C-35 citrange	5.60	7.68	9.48	14.10	21.00	32.40	36.22	40.33	41.50	42.12	48.00	53.66	29.34
Carrizo citrange	5.60	7.33	8.92	9.80	14.10	23.80	30.71	37.20	37.73	38.72	44.80	55.88	26.21
US-852	3.10	3.70	4.10	4.80	6.10	10.40	13.63	15.50	16.10	16.66	16.90	21.05	11.00
X-639	4.30	4.91	6.09	10.60	19.90	31.20	34.00	36.50	37.10	37.35	38.00	40.73	25.06
Swingle citrumelo	6.10	8.24	9.94	11.30	15.30	26.10	31.76	32.21	32.80	33.05	36.20	43.99	23.91
Gou Tou	4.30	6.10	10.10	12.63	14.70	21.30	24.58	26.03	26.80	27.44	30.40	31.44	19.65
Shin Chu Sha	3.00	4.20	5.40	7.30	9.40	15.10	18.72	21.54	22.30	23.04	28.19	32.20	15.86
Rangpur lime	5.20	7.60	9.59	10.00	12.30	21.70	26.33	28.66	29.30	29.64	31.20	34.66	20.51
Volkameriana	3.10	4.20	5.10	7.20	9.80	18.90	21.10	23.86	24.80	26.05	33.00	36.20	17.77
Rough lemon	3.30	4.60	5.26	7.20	10.90	22.00	26.44	28.22	30.00	31.08	33.10	36.99	19.92
Mean	4.47	6.07	7.53	9.29	12.95	21.42	25.58	28.01	28.80	29.42	32.55	37.44	

*DAS = Day After Sowing; CD (P=0.05); Interval (A) = 0.65; Rootstock (B) = 0.73; Interaction (A×B) = 2.53

and the minimum in Shin Chu Sha. Rootstocks after attaining the height of > 20 cm with proper flow of sap are considered suitable for citrus budding. The data show that the number of seedlings that reached buddable plant height at 210 DAS was significantly higher in C-35 citrange, followed by X-639 in comparison to Swingle citrumelo, Carrizo citrange, Troyer citrange, Benton citrange, Rough lemon, Rangpur lime, Guo Tou, and Kuharsuke citrange. Volkameriana lemon rootstock attained buddable plant height at an early stage of 240 DAS, Roubidoux trifoliate and Shin Chu Sha after 270 DAS; whereas, Rich 16-6 and US-852 achieved this stage much later than the other rootstocks under study. Mean plant height in C-35 citrange was recorded to be 2.67 times higher than US-852 while it was 2.07 and 1.94 times higher than Rich-16-6 and Rubidoux trifoliate respectively.

In general, all rootstocks put forth nearly 43.7 per cent of total vegetative growth between 180 to 240 DAS *i.e.* between July to September. However, the rate of growth was about 3.8 per cent in all the rootstocks under study between 300-330 DAS due to low temperatures in the months of November and December. Under protected conditions, short days and relatively low temperatures during the winter season effect different rootstocks variably for photosynthetic products and the amount of storage nutrients in their roots, eventually affecting the rate of main stem growth. Hafez (2006), while working on various citrus stocks, observed that Troyer citrange seedlings showed higher vegetative growth characteristics than Volkameriana lemon and Rangpur lime. Abou *et al.* (1995) found that Volkameriana lemon and Sour orange seedlings were superior in vegetative growth parameters than Rangpur lime. Singh *et al.* (2004) studied the growth performance of rough lemon seedlings under screen house conditions and observed that seedlings grown under screen house obtained more plant height as compared to the seedling grown under open field conditions.

Stem thickness: The effect of different rootstocks on the seedlings' thickness is given in Table 2 and the data reveals that it ranged from 3.07 to 4.74 mm; being minimum in US-852 and maximum in Swingle citrumelo. Nearly eight rootstocks achieved buddable stem thickness after 300 DAS in November and a higher increment to the tune of 45 per cent was observed between 180 DAS (July) to 270 DAS (October). After 270 DAS, Volkameriana lemon, Swingle citrumelo, Rough lemon, C-35 citrange and Carrizo citrange achieved maximum buddable thickness and values were 6.45, 6.41, 6.25, 6.19 and 6.03 mm, respectively, which were statistically at par with each other. Other rootstocks, X-639, Gou Tou and Kuharsuke citrange achieved stem thickness of 6.10, 6.04 and 6.01 mm, respectively after 300 DAS but these were statistically at par with each other. Swingle citrumelo had a 1.54 times higher mean stem thickness than US-852 and a 1.42 times higher mean stem thickness than Rubidoux Trifoliate.

Nasir *et al.* (2006) studied nursery performance of different rootstocks under Sargodha climate conditions and observed that rough lemon seedlings had shown maximum stem thickness followed by Rangpur lime and minimum in Kinnow rootstock. Similarly, Hafez (2006) observed that the stem thickness of Troyer citrange rootstock seedlings was significantly higher than Rangpur lime and Volkameriana lemon. Higher stem thickness in both lemon rootstocks and two citranges (C-35 and Carrizo) might be due to their vigorous growth behaviour. However, the slow growth habit of *Trifoliate* and their hybrids considerably influence stem thickness.

Average number of leaves: The cumulative enhancement of vegetative growth in terms of leaf number is shown in Table 3. The maximum average leaf number to the tune of 20.1 was observed in X-639, which was significantly higher than 18.5 in Rangpur lime and Carrizo citrange; 18.2 in Guo Tou and C-35 citrange and 18.0 in Shin Chu Sha. Whereas, Volkameriana and Rough lemon had leaf number to the tune of 16.1 and 16.0, which were statistically at par with each other. The lemon type rootstocks, Rough lemon and Volkameriana are quite vigorous and would be expected to have a relatively high growth rate and minimal branching, indicating a high degree of juvenility (Matheron *et al.,* 1998) and leaf number. Higher vegetative growth was noted in the month of July and August and was responsible for synthesis of carbohydrates and photosynthesis as cleared from corresponding values for plant height and stem thickness. Trifoliate rootstock and their hybrids shed their leaves in winter season due to their deciduous nature and further put forth vegetative growth in the spring season, hence a decrease in the

Table 2. Stem thickness at periodic intervals in exotic citrus rootstocks under protected conditions

Rootstock	Stem thickness (mm)												Mean
	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	210 DAS	240 DAS	270 DAS	300 DAS	330 DAS	360 DAS	390 DAS	
Rich 16-6	1.42	1.54	1.61	1.90	2.60	3.96	4.42	4.54	4.57	4.68	4.83	5.41	3.46
Rubidoux trifoliate	1.40	1.46	1.50	1.80	2.50	3.82	4.20	4.34	4.46	4.59	4.65	5.20	3.33
Benton citrange	1.59	1.83	1.94	2.24	3.04	4.74	5.45	5.86	5.94	6.00	6.19	6.86	4.31
Troyer citrange	1.52	1.79	2.03	2.32	3.02	4.96	5.40	5.69	5.80	5.88	6.16	6.74	4.28
Kuharsuke citrange	1.58	1.99	2.05	2.32	3.05	5.10	5.64	5.87	6.01	6.13	6.24	6.71	4.39
C-35 citrange	1.37	1.69	1.71	2.10	2.97	4.83	5.61	6.19	6.31	6.45	6.63	7.06	4.41
Carrizo citrange	1.59	1.93	1.98	2.28	2.98	4.95	5.47	6.03	6.15	6.26	6.43	6.85	4.40
US-852	1.30	1.35	1.41	1.75	2.25	3.34	3.75	3.95	4.05	4.18	4.37	5.13	3.07
X-639	1.30	1.39	1.44	1.74	2.43	4.36	5.06	5.99	6.10	6.23	6.35	6.84	4.10
Swingle citrumelo	1.87	2.09	2.24	2.54	3.24	5.25	5.87	6.41	6.52	6.66	6.81	7.35	4.74
Gou Tou	1.43	1.74	1.85	2.14	3.10	4.84	5.35	5.91	6.04	6.18	6.39	6.90	4.32
Shin Chu Sha	1.20	1.29	1.32	1.50	2.25	4.06	4.30	4.67	4.81	4.95	5.18	5.73	3.44
Rangpur lime	1.44	1.80	2.00	2.31	3.05	4.92	5.43	5.66	5.80	5.93	6.11	6.59	4.24
Volkameriana	1.26	1.30	1.42	1.61	2.50	4.41	5.84	6.45	6.58	6.70	6.96	7.38	4.37
Rough lemon	1.29	1.32	1.46	1.76	2.41	4.35	5.72	6.25	6.37	6.48	6.67	7.20	4.27
Mean	1.44	1.63	1.73	2.02	2.76	4.53	5.17	5.59	5.70	5.82	6.00	6.53	

*DAS = Day After Sowing; CD (*P*=0.05); Interval (A) = 0.40; Rootstock (B) = 0.45; Interaction (A×B) = 0.16

Table 3. Average number of leaves at periodic intervals in exotic citrus rootstocks under protected conditions

Rootstock	Average number of leaves												Mean
	60 DAS	90 DAS	120 DAS	150 DAS	180 DAS	210 DAS	240 DAS	270 DAS	300 DAS	330 DAS	360 DAS	390 DAS	
Rich 16-6	3.36	5.46	5.60	7.30	10.80	13.90	15.00	16.20	15.10	9.40	2.20	3.11	8.95
Rubidoux trifoliate	1.15	3.25	3.62	5.00	8.10	11.70	15.40	17.77	18.00	7.80	1.52	6.26	8.30
Benton citrange	5.10	7.20	8.70	10.10	13.3	20.40	24.55	26.88	27.00	16.40	4.37	21.26	15.44
Troyer citrange	3.36	5.46	5.73	7.20	10.2	16.40	24.33	28.66	27.40	12.70	10.44	18.63	14.21
Kuharsuke citrange	3.76	5.86	6.00	7.10	10.7	17.30	22.66	26.55	28.10	15.30	7.70	14.67	13.81
C-35 citrange	5.56	7.66	7.80	9.40	12.3	18.80	35.88	37.33	32.10	21.40	10.04	20.29	18.21
Carrizo citrange	4.56	6.66	7.00	8.30	11.5	25.90	32.77	34.88	35.40	26.90	10.92	17.41	18.52
US-852	1.80	3.40	3.80	4.00	6.10	11.30	13.88	15.11	13.70	5.20	2.89	9.52	7.56
X-639	3.50	5.60	5.73	7.90	11.80	28.10	39.33	42.00	36.80	24.80	15.90	19.59	20.10
Swingle citrumelo	4.10	6.20	6.80	8.10	11.30	17.80	18.33	25.88	26.20	15.70	8.33	19.26	14.00
Gou Tou	5.50	7.60	8.06	9.50	12.90	19.10	22.00	23.40	24.80	24.20	26.44	35.33	18.24
Shin Chu Sha	4.10	6.20	6.46	7.90	11.70	18.40	21.53	27.33	27.50	27.00	26.54	30.88	17.96
Rangpur lime	4.40	7.30	7.20	9.40	12.00	19.77	23.90	25.66	26.10	26.00	26.77	33.88	18.53
Volkameriana	3.10	6.20	7.00	8.10	10.60	16.33	18.90	21.60	22.50	23.40	24.00	31.55	16.11
Rough lemon	3.30	5.40	5.73	7.80	11.00	18.90	19.22	20.22	21.70	22.00	24.11	32.88	16.02
Mean	3.78	5.96	6.35	7.81	10.95	18.27	23.18	25.96	25.49	18.55	13.48	20.97	

*DAS = Day After Sowing; CD (*P*=0.05); Interval (A) = 0.12; Rootstock (B) = 0.14; Interaction (A×B) = 0.48

number of leaves was observed after 300 DAS. This is related to genotype behavior of the rootstocks. In some mediums, fewer leaves are also a common morphological feature of some plant varieties, resulting in significant variation between rootstocks. Also, slower growth in terms of plant height in some rootstocks might have resulted in lesser leaf number. Hafez (2006), while working on evaluation of growth characteristics of various citrus stocks for two consecutive years, observed that Rangpur lime, sour orange and Troyer registered leaf number to the tune of 44.7 and 45.4, 13.6 and 14.8, and 24.1 and 29.5, respectively.

Root characters (at buddable stage)

Root length: The effect of different rootstocks on root length is illustrated in Table 4. The data revealed that root length significantly varied among different rootstocks. The maximum root length of 35.3 cm was recorded in Volkameriana followed by Rangpur lime, Carrizo citrange, Benton citrange, X-639, Kuharsuke citrange, Swingle citrumelo, C-35 citrange and Rough lemon. All these rootstocks registered non-significant variation with each other. More than double (2.3 times) root length was observed in Volkameriana lemon in comparison to Rich 16-6 and this might be due to the vigorous growth character of this rootstock which would have promoted higher root mass in terms of length to maintain root-shoot ratio. The variation in root length in different rootstocks may be due to the difference in genetic behaviour of each genotype. Differences in vegetative growth pattern of rootstocks might also have contributed to varied root length in these stocks. Chahal and Sidhu (2015) while working on different methods of cuttings for propagation of Carrizo citrange found maximum root length to the tune of 22.2, 18.1 and 16.2 cm in hardwood, semi-hardwood and soft wood cuttings, respectively.

Root thickness: It is pertinent to mention that root thickness among different rootstocks growing under protected conditions has shown a lot of variation (Table 4) and it ranged from 3.75 to 5.95 mm. Benton citrange produced the thickest root system at 5.95 mm in diameter. It showed non-significant variations with Carrizo citrange, Volkamerana lemon, Rangpur lime, Swingle citrumelo, C-35 citrange, Kuharsuke citrange, Shin Chu Sha, X-639 and Rough lemon. Rich 16-6 rootstock seedlings produced just 63 per cent root thickness in comparison to Benton citrange, while US-852 and Rubidoux trifoliate recorded 70 and 72 per cent root thickness against maximum value. Singh *et al.* (2015) studied the effect of different growing seasons, rooting media, and PGRs on average root diameter in lemon cultivar Pant lemon-1 propagated through cutting and found it ranged from 0.95 to 1.24 mm.

Fresh weight of roots: Data regarding root fresh weight mentioned in Table 4 suggested that Rangpur lime rootstock had maximum (6.05 g) fresh root weight followed by Carrizo citrange, Shin Chu Sha, Rough lemon, C-35 citrange than the rest of rootstocks under the present study. However, lower values for root fresh weight were observed in Rich 16-6, Rubidoux trifoliate and US-852. Rich 16-6 produced only 37 per cent of the root fresh weight as against Rangpur lime, while Rubidoux trifoliate and US-852 recorded 40 and 50 per cent values in comparison to the maximum fresh weight of roots registered.

Dry weight of roots: Generally, root dry weight is directly proportionate to root fresh weight. In the present study, a similar trend was also observed and maximum (3.50 g) dry weight was found in Rangpur lime and minimum (1.40 g) in Rich 16-6. C-35 citrange, Carrizo citrange, X-639, Shin Chu Sha, Volkameriana and Rough lemon rootstocks were statistically non-significant with each other than the highest in Rangpur lime.

Chahal and Sidhu (2015) studied the root dry weight of Carrizo citrange during their work on propagation of this rootstock through different methods. They registered this parameter ranged from 1.72 to 2.68 g. In the same study, the fresh root weight of Carrizo citrange rootstock was estimated as 3.89 g in plants produced from hardwood cuttings, 3.30 g in semi-hardwood cuttings and 2.88 g in softwood cuttings. However, all the cutting types failed to produce any significant variation in terms of root fresh weight.

Plant dry weight at buddable stage: Plant dry weight of different rootstock seedlings at 390 DAS were statistically significant (Table 5). The variability in dry weight ranged from 3.61 to 10.5 g. According to the data, the highest plant dry weight at the budabble stage was recorded in C-35 citrange, which was

Table 4. Root characters of exotic citrus rootstocks grown under protected conditions

Rootstocks	Root length (cm)	Root thickness (mm)	Fresh weight of roots (g)	Dry weight of root (g)
Rich 16-6	15.3	3.75	2.26	1.40
Rubidoux trifoliate	30.3	4.30	2.40	1.57
Benton citrange	33.2	5.95	4.55	2.73
Troyer citrange	27.3	4.78	3.75	2.08
Kuharsuke citrange	32.7	5.47	4.01	2.39
C-35 citrange	32.0	5.48	5.25	3.39
Carrizo citrange	34.0	5.82	5.78	3.29
US-852	21.0	4.17	3.05	1.94
X-639	33.0	5.15	4.80	3.05
Swingle citrumelo	32.0	5.55	4.25	2.64
Gou Tou	30.7	4.44	4.50	2.49
Shin Chu Sha	30.0	5.20	5.70	3.31
Rangpur lime	34.2	5.58	6.05	3.50
Volkameriana	35.3	5.60	4.90	3.13
Rough lemon	31.7	5.05	5.27	3.17
CD (*P*=0.05)	3.67	1.01	1.26	0.57

comparable to Shin Chu Sha, Carrizo citrange, and Rough lemon, and significantly lower in Trifoliate rootstocks, namely Rich 16-6, Rubidoux trifoliate, and US-852.Rich-16-6 and Rubidoux trifoliate resulted in less than 50 per cent of the plant dry weight as compared to the maximum value produced by C-35 citrange. Troyer citrange, Swingle citrumelo, Kuharsuke citrange, Gou Tou, Benton citrange, Volkameriana, and Rangpur lime rootstocks had dry weights ranging from 6.4 to 9.7 g at the buddable stage. Higher plant dry weight at the buddable stage in C-35, Carrizo citrange, and Rough lemon could be attributed to increased vegetative growth in terms of plant height and stem thickness. Rich 16-6, Rubidoux trifoliate and US-852 must have attained a lower level of plant dry weight due to less number of leaves/ plant. Similarly, Bhagat *et al.* (2013) reported that rough lemon seedlings had reached a maximum plant dry weight of 16.1 g at the buddable stage.

Budding success: Generally, the bud intake depends upon the stem thickness, flow of sap and season of budding. Most rootstocks under study attained suitable growth for budding within 270 to 390 days after seed sowing. The highest budding success was obtained in Rough lemon, Volkameriana lemon, Rangpur lime and Kuharsuke citrange and values were 81.9, 78.9, 77.5 & 72.5 per cent, respectively. However, the results were statistically at par with each other. Rich 16-6 and US-852 rootstocks had < 50 per cent bud intake success and values were 46.4 and 47.3 per cent, respectively. Rubidoux trifoliate registered 53.8 per cent success intake and was statistically at par with Rich 16-6 and US-852. Swingle citrumelo and Benton Citrange recorded success rates of 58.9 and 58.2 per cent, respectively. The rootstocks showing a success rate of between 60 to 70 per cent were C-35 citrange, Carrizo citrange, Troyer citrange, Gou Tou & Shin Chu Sha and these were statistically at par with each other.

Table 5. Plant dry weight at buddable stage and budding success of exotic citrus rootstocks under protected conditions

Rootstocks	Dry weight at buddable stage (g)	Budding success of kinnow (%)
Rich 16-6	3.6	46.4
Rubidoux trifoliate	4.4	53.8
Benton citrange	8.5	58.2
Troyer citrange	6.4	67.7
Kuharsuke citrange	7.5	72.5
C-35 citrange	10.5	60.1
Carrizo citrange	10.1	64.0
US-852	5.9	47.3
X-639	7.7	69.5
Swingle citrumelo	7.3	58.9
Gou Tou	8.4	69.4
Shin Chu Sha	10.2	69.5
Rangpur lime	9.7	77.5
Volkameriana	8.5	78.9
Rough lemon	10.0	81.9
CD (*P*=0.05)	0.76	11.45

The high level of budding success in Rough lemon, Volkameriana, and Rangpur lime could be attributed to their evergreen nature, which resulted in the retention of leaves even in December and January, resulting in regular movement of photosynthates and superior sap flow during the budding month. Poor budding success in Trifoliates and their hybrid US-852 might be due to their deciduous nature, less leaf number and comparatively thin stem size. Also, during propagation, usually two genetically different plant materials are combined to form the citrus tree. The relationship between scion and stock, which is commonly termed affinity or compatibility, is of fundamental importance to successful long-term commercial performance (Castle *et al.,* 1993). This phenomenon may be due to genetic or physiological incongeniality and can be the major reason for fluctuating budding success among different rootstocks.

Nasir *et al.* (2006) during the study on nursery performance of rootstocks of different citrus species under Sargodha climate conditions recorded the budding success percentage of Kinnow scion on Ranpur lime, Rough lemon, and Kinnow rootstocks being maximum (95.1 per cent) in Rangpur lime followed by Rough lemon (92.6 per cent) and minimum (91.5 per cent) in Kinnow.

Keeping in view the outcome of the present study in relation to seedling growth, rooting characters and budding success of Kinnow plants on diverse rootstock types, it is suggested that Rough lemon, Volkameriana lemon, Rangpur lime and Kuharsuke citrange rootstocks can be exploited for the production of quality nursery plants under protected conditions. However, their long term effects on fruit yield and quality need to be critically taken into consideration before coming to conclusion.

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