



Original Research

Effect of Rootstocks on Physico-Morphological Performance of Kinnow Mandarin under Agro-Climatic Conditions of Pakistan

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ABSTRACT

This study evaluated the impact of nine rootstocks on yield and fruit quality of Kinnow mandarin (*Citrus reticulata* Blanco) under the agro conditions of Punjab, Pakistan, using a randomised complete block design over two consecutive years. Rootstocks significantly influenced key productivity parameters: *Poncirus trifoliata* produced the highest yield (37.68 kg tree⁻¹), largest fruit diameter (75.58 mm), and highest fruit set (54.74%), while minimising preharvest drop (28.14%). In stark contrast, Troyer citrange demonstrated poor performance, yielding only 19.41 kg tree⁻¹ with 48.59% preharvest drop. The Fraser hybrid emerged as a viable alternative (24.43 kg tree⁻¹; 50.35% fruit set). Peel thickness varied significantly, with C-35 inducing the thickest rind, whereas Troyer citrange yielded the thinnest peel. Rootstocks exerted no significant influence on fruit morphology (shape, colour, oil gland density), seed count, or segment number, confirming genetic stability in these traits. The superior performance of *Poncirus trifoliata* aligns with its documented drought tolerance in water-limited environments, while Troyer citrange's failure highlights critical genotype × environment interactions. We recommend *Poncirus trifoliata* as the optimal rootstock for Kinnow in semi-arid regions, boosting yields 94% over Troyer citrange. The Fraser hybrid offers a robust secondary option for diversified orchard management. Future studies should assess the long-term soil health implications and disease resistance of *Poncirus trifoliata*.

Keywords: *Citrus* rootstocks, Kinnow mandarin, *Poncirus trifoliata*, fruit yield, preharvest drop.

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INTRODUCTION

Citrus (*Citrus reticulata* L.) maintains a crucial status in the global fruit sector, cultivated extensively across tropical and subtropical zones worldwide. Primary citrus cultivation areas are focused between 40°N and 40°S latitudes. Classified within the Rutaceae family under subfamily Aurantioideae, citrus includes 28 genera in the tribe Citreae (Swingle and Reece, 1967). Regarding commercial production, citrus is grown in 53 nations with an output of 137.8 million tonnes. China leads production volumes at 29.65 million metric tonnes, followed by

Brazil (18.96 million metric tonnes) and the USA (10.01 million metric tonnes) (FAO, 2019).

Rootstocks influence fruit mass and dimensions. The Okitsu mandarin fruit varied significantly in size depending on the rootstock. Superior fruit sizes emerged from Orlando tangelo grafts (Aviles et al., 2010). Similarly, Stenzel and Neves (2004) observed no rootstock impact on Tahiti lime fruit dimensions. Likewise, Fallahi and Rodney (1992) indicated that Fairchild mandarin exhibited greater fruit mass on Taiwanica versus other rootstocks. Correspondingly, Hameed et al. (2018) documented maximum fruit weight for Kinnow mandarin on Volkamer lemon, trailed by Brazilian sour rootstock, whereas Carrizo citrange yielded minimal fruit weight. Tazima et al. (2013) in Brazil noted rootstock effects on fruit mass, with grafts on C-13, Carrizo citrange, and Sunki mandarin generating the largest fruits. In comparable research, Navelina orange produced its heaviest fruits on Volkamer lemon and C-35 citrange among fourteen rootstocks (Giner et al., 2003).

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Table 1: Morphological description Kinnow fruits on different rootstocks.

Rootstocks	Fruit shape	Fruit skin colour	Fruit surface texture	Density of oil glands*
Rough lemon	Spheroid	Orange	Smooth	Intermediate
Cox mandarin	Spheroid	Orange	Smooth	Intermediate
Fraser hybrid	Spheroid	Dark orange	Smooth	High
Troyer citrange	Spheroid	Orange	Rough	Intermediate
Cleopatra mandarin	Spheroid	Orange	Smooth	High
<i>Poncirus trifoliata</i>	Spheroid	Orange	Smooth	High
Benton	Spheroid	Orange	Rough	Low
C-35	Spheroid	Orange	Smooth	Intermediate
Carrizo citrange	Spheroid	Orange	Smooth	Intermediate

* Low (<40 cm⁻²), Intermediate (45-65 cm⁻²), High (>70 cm⁻²).

Similarly, Bassal (2009) in Egypt examined Marisol Clementine budded onto four rootstocks. Filho et al. (2007) reported that rootstocks did not significantly affect the fruit mass of Fallglo and Sunburst mandarins. However, Smith et al. (2004) found that Ellendale mandarin on Lockyer rootstock developed substantially heavier fruits than other grafts. Comparatively, Macrophylla and Volkamer lemon rootstocks yielded the heaviest Allen Eureka lemon fruits versus other rootstocks (Al-Jaleel et al., 2005). Likewise, Sharma et al. (2002a) noted that Kinnow mandarin produced its heaviest fruits on Jatti Khatti rootstock under Punjab's arid-irrigated conditions.

Zekri et al. (2004) reported increased fruit mass on rough lemon, Citrus macrophylla, and Volkamer lemon, whereas smaller fruits occurred on Sour orange and Cleopatra mandarin. McCollum et al. (2017) demonstrated significant rootstock impacts on fruit dimensions: 'Sour orange' and 'Swingle' produced the largest fruits, while US-897 formed the smallest. Zekri (2000) observed maximum fruit sizes from Volkamer lemon and minimum from Cleopatra mandarin. Sharma et al. (2002a) found that Kinnow mandarin on Jatti Khatti and Karna Khatta developed thick peels, whereas Troyer and Carrizo yielded thin peels. In additional findings, Sharma et al. (2002b) stated that Campbell Valencia fruits exhibited thick peels on Karna Khatta but thin peels on Troyer.

Hussain et al. (2013) assessed Common clementine performance on nine rootstocks over 11 years, finding Carrizo citrange achieved the highest productivity, while Da Hang Pao mandarin and Gou Tou sour orange resulted in the lowest. Similarly, Smith et al. (2004) evaluated seven Australian rootstocks for Ellendale mandarin, observing maximum yields with Lockyer Rough lemon and lowest yields with Emperor mandarin. Tazima et al. (2013) found that Swingle Citrumello rootstock enhanced both growth and fruit production in Satsuma mandarin during their 2003-2011 study. In contrast, Okitsu satsuma mandarin grafted onto Volkamer lemon showed consistently low yields throughout the experimental period.

MATERIALS AND METHODOLOGY

A two-year study was conducted at the Postgraduate Agricultural Research Station (PARS), University of Agriculture Faisalabad (31°23'20"N, 73°0'09"E), to assess how different rootstocks affect the yield and fruit quality of Kinnow mandarin (*Citrus reticulata* Blanco). The Faisalabad region experiences an average annual temperature of 25.74°C and receives 346 mm of

rainfall. The investigation compared Kinnow trees grafted onto nine rootstocks: Rough lemon (*Citrus x limon* [L.] Osbeck) - used as the control due to its prevalence as the commercial rootstock in Punjab - along with Cox mandarin (*P. trifoliata* x *C. reticulata*), Fraser hybrid (*Seville* x *P. trifoliata*), Troyer citrange (*Poncirus trifoliata* [L] Raf x *Citrus sinensis* [L] Osbeck), Cleopatra mandarin (*Citrus reshni* Hort. ex Tanaka), *Poncirus trifoliata* (*Poncirus* Raf.), Benton citrange (*Citrus sinensis* [L.] Osbeck x *Poncirus trifoliata* [L.]), C-35, and Carrizo citrange (*C. sinensis* Osbeck x *Poncirus trifoliata*).

Trees were planted in a square pattern with 18 x 18 feet spacing. Irrigation involved a heavy watering every two weeks, supplemented by an additional heavy irrigation two weeks prior to flowering initiation. Annual fertiliser application followed recommended NPK levels (1000:500:500 g per tree) to support vegetative and reproductive growth. Nitrogen was split into two applications: half combined with the full phosphorus and potassium dose in February, and the second half applied in April after fruit set. To maintain soil organic matter, 50 kg of well-rotted farmyard manure (FYM) was applied each December. Data collected over the two consecutive seasons included yield parameters (fruit set percentage, fruit drop percentage, and total yield per tree) and fruit quality attributes (based on morphological and physical characteristics).

Experiment layout and design

- Rootstocks: 9
- Scions: 1
- Replications: 3
- Experimental Design: RCBD
- Each rootstock was considered a treatment

Estimation of morpho-physical quality attributes

Morphology

Morphology of Kinnow was evaluated according to the citrus descriptors developed by the International Plant Genetic Resource Institute (IPGRI).

Fruit diameter (mm)

For each experimental replicate, thirty fruits were randomly selected, and their equatorial diameter was measured with Vernier callipers. The average fruit diameter was then

determined and expressed in millimetres.

Peel thickness (mm)

Using a Vernier calliper, peel thickness was measured on thirty randomly selected fruits per replication. The mean value was calculated and reported in millimetres.

Seed count

Ten fruits from each replication were selected and twisted to extract the seeds. The total number of viable seeds was counted.

Number of segments

Fruits from each replication were peeled, and the number of segments was recorded.

Fruit set percentage

Following bloom completion, fruit set percentage for Kinnow fruits across rootstocks was assessed from mid-April through late April. The formula below was used to calculate fruit set percentage based on fruit counts from tagged branches.

$$\text{Fruit set percentage} = \frac{\text{Total fruit set on tagged branches}}{\text{Total number of flowers tagged}} \times 100$$

Fruit drop percentage

Kinnow fruit drop percentage was monitored during three developmental phases: button drop, June drop, and pre-harvest drop. Monthly fruit counts from tagged branches were used to calculate drop percentages according to the established formula.

$$\text{Fruit drop percentage} = \frac{\text{Total number of fruit drop}}{\text{Total fruit set}} \times 100$$

Yield per tree (kg)

Yield per tree was calculated by multiplying the average weight of the fruits by the number of fruits and expressed in kilograms.

RESULTS

Morphological description of citrus fruit

The fruit morphology of Kinnow grafted on different rootstocks was observed based on fruit shape, fruit skin colour, fruit surface texture and density of oil glands. These traits were recorded according to the citrus descriptors developed by IPGRI. No significant effect of rootstock on the morphological traits of Kinnow fruit was observed. Detail of the morphological traits of Kinnow mandarin on different rootstocks is given in Table 1

Fruit diameter (mm)

The mean of both years combined indicated that *Poncirus trifoliata* produced the largest fruit diameter (75.58 mm) (Fig. 1). Cox mandarin (60.46 mm), Fraser hybrid (60.41 mm), C-35 (62.37 mm), and Carrizo citrange (63.78 mm) displayed statistically comparable performance. During 2017, Kinnow

mandarin fruits attained maximum diameter (67.12 mm) on *Poncirus trifoliata*, while the smallest fruits (42.56 mm) occurred on Troyer citrange. Fruit diameters on other rootstocks were: Rough lemon (50.19 mm), Cox mandarin (52.18 mm), Fraser hybrid (49.69 mm), Cleopatra mandarin (46.56 mm), Benton (49.06 mm), C-35 (61.34 mm), and Carrizo citrange (61.03 mm).

Peel thickness (mm)

The two-year mean peel thickness revealed C-35 had the thickest peel overall, followed by *Poncirus trifoliata* (Fig. 2). Cox mandarin, Fraser hybrid, Cleopatra mandarin, Benton, and Carrizo citrange exhibited statistically similar peel thickness. The thinnest peel was recorded on Troyer citrange.

Seed count

Analysis of the combined biennial mean showed no significant differences among rootstocks (Fig. 3). The highest seed count originated from *Poncirus trifoliata*. Cox mandarin, Fraser hybrid, Troyer citrange, and Benton citrange displayed intermediate seed numbers and were statistically equivalent. Cleopatra

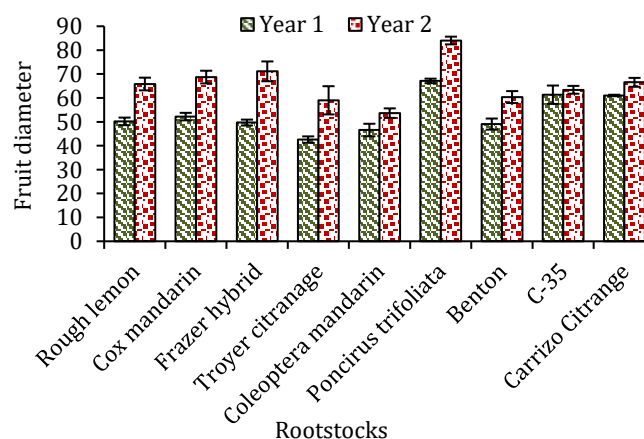


Figure 1: Effect of various rootstocks on fruit diameter of Kinnow mandarin.

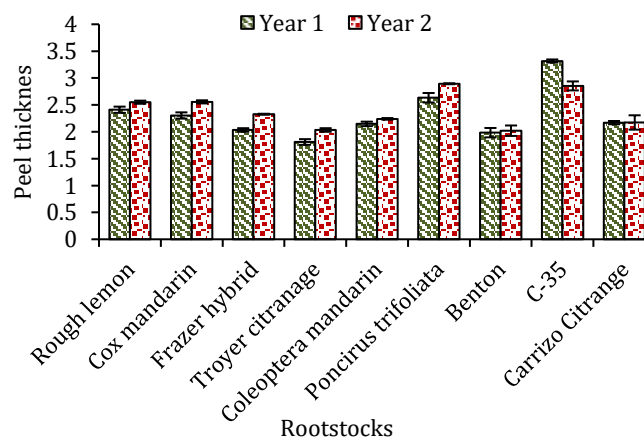


Figure 2: Effect of various rootstocks on peel thickness of Kinnow mandarin.

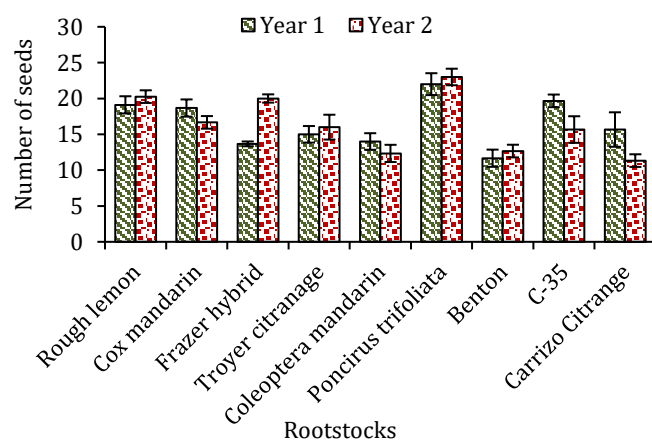


Figure 3: Effect of various rootstocks on number of seeds of Kinnow mandarin.

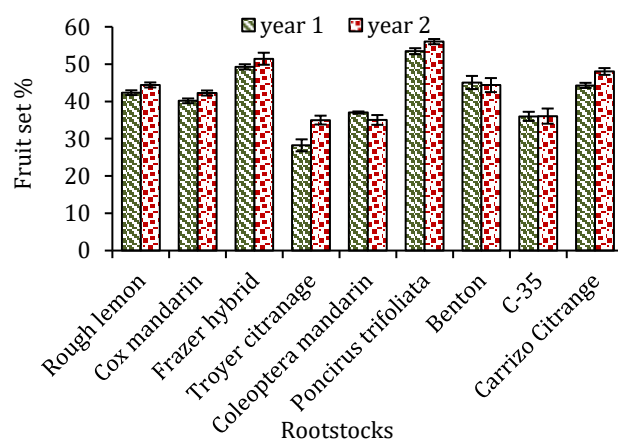


Figure 5: Effect of various rootstocks on fruit set percentage of Kinnow mandarin.

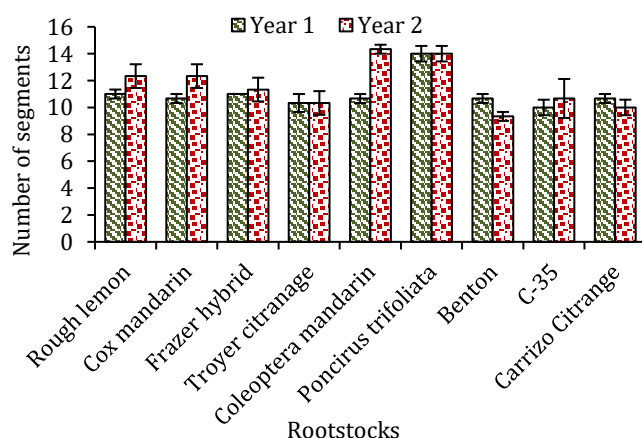


Figure 4: Effect of various rootstocks on number of segments of Kinnow mandarin.

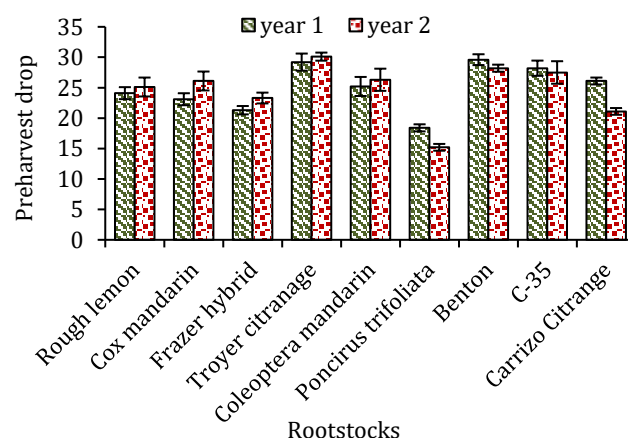


Figure 6: Effect of various rootstocks on preharvest drop of Kinnow mandarin.

mandarin, Benton, and Carrizo citrange yielded the lowest seed counts, with no significant differences between them.

Number of segments

The combined biennial mean demonstrated that *Poncirus trifoliata* rootstock produced the highest segment count (14.0). At the same time, Troyer citrange yielded the fewest (10.0) (Fig. 4). All rootstocks except *Poncirus trifoliata* were statistically similar, with non-significant differences. An average of ten segments per Kinnow fruit occurred across these rootstocks. Thus, it can be inferred that rootstocks do not influence segment number in Kinnow mandarin.

Fruit set percentage (%)

Fruit set represents the most decisive stage for fruit-bearing trees, determining ultimate yield potential (Fig. 5). Total fruit set on tagged branches was assessed in early April, the optimal period for such measurements. Based on pooled biennial data, *Poncirus trifoliata* (54.74%) and Fraser hybrid (50.35%) demonstrated superior performance relative to other rootstocks. Benton and Carrizo citrange showed statistically

comparable results. Troyer citrange exhibited notably poor performance.

Preharvest fruit drop (%)

Preharvest fruit drop constitutes the most significant category of fruit shedding, directly affecting final tree productivity (Fig. 6). Combined biennial means revealed higher drop percentages for Troyer citrange (48.59%), Carrizo citrange (43.63%), and C-35 (38.35%), contributing to reduced yields from these rootstocks. During 2017, maximum preharvest fruit drop (49.21%) occurred on Troyer citrange, followed by Carrizo citrange (46.11%). Other rootstocks displayed the following drop rates: Rough lemon (34.10%), Cox mandarin (35.16%), Fraser hybrid (40.47%), Cleopatra mandarin (35.29%), *Poncirus trifoliata* (28.14%), Benton (39.60%), and C-35 (40.92%).

Total yield (kg)

Total yield data were recorded over two consecutive growing seasons (Fig. 7). Combined biennial means indicated *Poncirus trifoliata* as the highest-yielding rootstock (37.679 kg) for Kinnow, followed by Fraser hybrid (24.43 kg), while Troyer

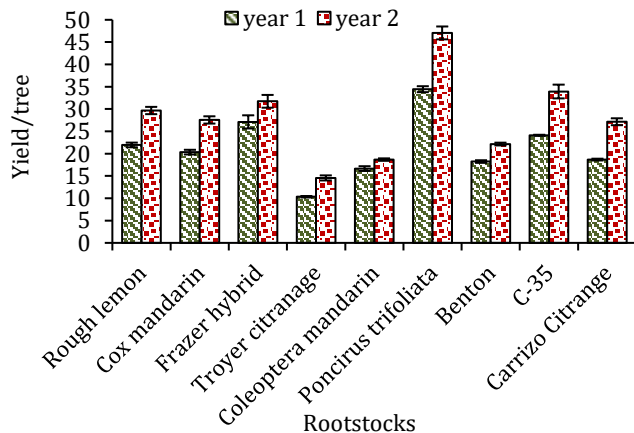


Figure 7: Effect of various rootstocks on yield/tree percentage of Kinnow mandarin.

citrange demonstrated notably low productivity (19.41 kg) for Kinnow mandarin.

DISCUSSION

This study establishes that rootstock selection profoundly impacts Kinnow mandarin productivity and fruit quality under Northwest India's arid-irrigated conditions. *Poncirus trifoliata* emerged as the optimal rootstock, delivering superior yield (37.68 kg tree⁻¹), fruit diameter (75.58 mm), and fruit set (54.74%) while minimising preharvest drop (28.14%). These results align with global studies attributing trifoliate rootstock efficacy to enhanced drought tolerance and nutrient partitioning (Hussain et al., 2013; Tazima et al., 2013), particularly critical in Punjab's water-scarce environment. By contrast, Troyer citrange consistently underperformed, exhibiting the highest preharvest drop (48.59%) and lowest yield (19.41 kg)—a stark reversal of its reported success in Mediterranean climates (Giner et al., 2003). This divergence underscores the *genotype × environment* interactions governing rootstock performance, with Troyer's shallow root system proving maladapted to arid regions. Fraser hybrid demonstrated reliable secondary performance (yield: 24.43 kg; fruit set: 50.35%), offering a viable alternative for diversified orchard planning.

Notably, rootstocks exerted minimal influence on core morphological traits (fruit shape, colour, oil gland density; Table 1), confirming Kinnow's genetic stability. However, peel thickness varied significantly, with C-35 producing the thickest rind, consistent with Sharma et al. (2002a), who associated this trait with reduced pest vulnerability. Troyer's thin peel further compounded its agronomic limitations. Seed count and segment number remained largely rootstock-insensitive (excepting *Poncirus*' elevated segments), supporting Filho et al. (2007) on scion-dominant genetic control. This stability is commercially advantageous, ensuring uniform fruit morphology across rootstocks.

Our findings partially realign regional rootstock recommendations: *Poncirus*' dominance in fruit size/yield contrasts with Hameed et al. (2018), who observed Kinnow's maximum weight on Volkamer lemon, but validates Punjab-

specific studies (Sharma et al., 2002b) advocating Jatti Khatti for similar traits. Troyer's high drop aligns with Smith et al. (2004) in Australian trials, yet its catastrophic failure here highlights *climate-specific thresholds* for rootstock resilience. Fraser hybrid's intermediate performance mirrors Bassal (2009) observations in Egypt, suggesting broad adaptability. *Poncirus trifoliata* should replace traditional rootstocks in Punjab's Kinnow orchards to boost yield by ≈94% over Troyer while reducing preharvest losses. Future research must address unanswered questions: *Poncirus*' long-term soil health impacts, salinity tolerance, and compatibility with local pathogens (*Phytophthora* spp.)—factors critical for sustainable adoption. Regionally, these results necessitate a paradigm shift toward *climate-tailored rootstock selection* over generic global recommendations.

CONCLUSION

Poncirus trifoliata is the optimal rootstock for Kinnow mandarin in arid Northwest India, maximising yield (37.68 kg tree⁻¹), fruit size (75.58 mm), and fruit set (54.74%) while minimising preharvest drop (28.14%). Troyer citrange performed poorly (yield: 19.41 kg; drop: 48.59%), demonstrating critical genotype × environment interactions. Rootstocks did not alter fruit morphology or segment number but influenced peel thickness (C-35 produced the thickest rind). We recommend *Poncirus trifoliata* to boost yields up to 94% over Troyer. Future studies should assess its long-term soil impacts and disease resistance.

DECLARATION OF COMPETING INTERESTS

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION STATEMENT

Muhammad Ahsan Qureshi: Conducted the experiments and wrote the manuscript. **Muhammad Jafar Jaskani:** Supervised the research and improved the write-up. **Naseem Shareef:** Data analysis. **Ejaz Ashraf, Safeer Ud Din, Muhammad Shahzad Zafar:** Reviewed and revised the article.

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ETHICAL STATEMENT

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

All data is published in this research article.

INFORMED CONSENT

Not applicable.

CONSENT FOR PUBLICATION

All authors have submitted consent to publish this research article in the 'Journal of Horticulture Science and Technology'.

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