



## Effect of rootstocks on growth, yield, fruit quality and leaf nutrients of Khasi mandarin (*Citrus reticulata*)

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Received: 29 August 2025; Accepted: 19 November 2025

### ABSTRACT

The present study was carried out during 2023 and 2024 at ICAR-Research Complex for NEH Region, Umiam, Meghalaya to examine the influence of seven rootstocks comprising *Citrus karna* Raf., *Poncirus trifoliata* (L.) Raf., *Citrus jambhiri* Lush., *Citrus limonia* (L.) Osb., *Citrus latipes* (Swingle) Yu. Tanaka, *Citrus taiwanica* (Tan. & Shim.) and *Citrus volkameriana* (Ten. & Pasq.) on the growth, yield, fruit quality and leaf mineral composition of Khasi mandarin (*Citrus reticulata*). Results indicated significant difference in growth parameters, with *Citrus jambhiri* Lush. showing superior plant height, trunk girth and canopy spread as compared to other rootstocks. With regards to the yield parameters, Khasi mandarin plants grafted on *Citrus limonia* (L.) Osb. recorded maximum yield, fruit size, number of segments and juice content whereas number of fruits per tree and fruit weight were highest with *Citrus jambhiri* Lush and *Citrus volkameriana* (Ten. & Pasq.), respectively. Biochemical traits of the fruits were showing superiority in *Citrus volkameriana* (Ten. & Pasq.). The rootstocks also imparted significant influence on the leaf nutrient contents. Plants on *Citrus jambhiri* Lush had the highest level of leaf nitrogen, phosphorus, potassium, calcium, and iron, while those on *Citrus limonia* (L) Osb. had the highest levels of magnesium, zinc, and copper. Based on the overall performance in growth, yield, fruit quality and nutrient accumulation patterns, *Citrus jambhiri* Lush., *Citrus limonia* (L) Osb. and *Citrus volkameriana* (Ten. & Pasq.) can be recommended as suitable rootstocks for the Khasi mandarin.

**Keywords:** Citrus, Nutrient status, Physico-chemical, Stionic influence

Khasi mandarin (*Citrus reticulata*), is among the most well-known citrus species in the north-eastern region. The fruits have a bright orange-yellow colour, glossy smooth loose skin, medium to thick peel, and easily removable segments (Deshmukh *et al.* 2017). Khasi mandarin with its unique blend of sugar and acid, is renowned for its distinct sweet and sour taste. Being non-climacteric fruit, it is also reported to have a good shelf life (Ngachan *et al.* 2010, Barbora *et al.* 2019). Geographical Identification (GI) was obtained for this crop in the year 2014 due to its unique quality (Rymbai *et al.* 2022). Although the region has great potential, the productivity of Khasi mandarin (6.14 t/ha) remains considerably below the national average of 13.4 t/ha (Anonymous 2023). According to Patel *et al.* (2010), most mandarin orchards in the region are established from seedling however recently, there has been a growing demand for vegetatively propagated plants for use in commercial orchards (Talang *et al.* 2024). Numerous researchers have

documented the influence of rootstocks on the scion cultivars under various agro-climatic conditions. Josan and Thatai (2008) and Kumar *et al.* (2022) reported from rootstock trials that Jatti Khatti is suitable rootstock for Kinnow mandarin in Punjab and Jammu region. Sonkar *et al.* (2011) studied the performance of Nagpur mandarin on five strains of Rough lemon and eleven strain of Rangpur lime under sub-humid climate of central India and recorded compatible stionic combination of Nagpur mandarin on all tested rootstocks. Similarly, Sau *et al.* (2018) reported maximum yield of Nagpur mandarin grafted on Rough lemon and Gandharaj in West Bengal. The effect of rootstocks on the nutrient accumulation pattern of citrus cultivars has also been reported in studies involving Coorg and Kinnow mandarin (Iyengar *et al.* 1982), Grapefruit (Sharma *et al.* 2015) and Kagzi Kalan lemon (Dubey and Sharma 2016). Although rootstocks impart a positive influence on the scion grafted on it, rootstock trials must be carried out to find suitable rootstocks for particular agro-climatic condition (Kumar *et al.* 2017). In case of Khasi mandarin, little information is available on the suitable rootstock for its vegetative propagation. In light of the above, the present study was designed to examine the impact of various rootstocks on the growth, yield, fruit quality, and leaf mineral composition

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of Khasi mandarin, with the objective of offering valuable insights to enhance mandarin cultivation in the north-eastern region of India.

## MATERIALS AND METHODS

The present study was carried out during 2023 and 2024 at ICAR-Research Complex for NEH Region, Umiam (25°41'N, 91°55'E; at an elevation of 1010 m amsl), Meghalaya. Around 90% of the total annual rainfall, which measured 2160.15 mm, occurred between May and October. The recorded minimum temperature was 7.5°C in January, while the maximum reached 28.4°C in June. Relative humidity varied seasonally, with the lowest at 40.8% during winter and the highest at 90.5% during the monsoon period.

**Plant material:** A five year old orchard of Khasi mandarin, grafted following the wedge grafting method onto seven different rootstocks comprising T<sub>1</sub>, *Citrus karna* Raf.; T<sub>2</sub>, *Poncirus trifoliata* (L.) Raf.; T<sub>3</sub>, *Citrus jambhiri* Lush.; T<sub>4</sub>, *Citrus limonia* (L) Osb.; T<sub>5</sub>, *Citrus latipes* (Swingle) Yu. Tanaka; T<sub>6</sub>, *Citrus taiwanica* (Tan. & Shim.); and T<sub>7</sub>, *Citrus volkameriana* (Ten. & Pasq.) were selected for the study. The plants were planted at a spacing of 5 m × 5 m using a randomised block design (RBD), with three replications for each treatment.

**Soil analysis:** The physico-chemical properties of the soil at the experimental site were Nitrogen 235.31 mg/kg; Phosphorus 6.22 mg/kg; Potassium 203.95 mg/kg; Organic Carbon 1.46%; pH 4.82; Ca 225.12 mg/kg; Mg 55.90 mg/kg; Iron 36.37 mg/kg; Zinc 2.35 mg/kg; Copper 1.09 mg/kg; and Manganese 10.62 mg/kg.

**Growth and yield parameters:** Plant height, canopy spread, and trunk girth (measured 5 cm above the graft union) were recorded using a meter scale during December–January. The total number of fruits/plant was counted prior to harvest. Fruit weight and peel weight were determined by weighing 20 randomly selected fruits using an analytical electronic balance. Fruit yield/tree was calculated by multiplying the average fruit weight by the total number of fruits on the tree. Fruit length and width were measured with a Vernier caliper. The number of segments and seeds was recorded from 20 randomly selected fruits.

**Biochemical parameters:** The juice contents were weighed and expressed in percentage (Lacey *et al.* 2009). Total Soluble Solids (TSS) were determined with a digital refractometer, while acidity, ascorbic acid and sugars were analysed following the standard procedures outlined by Ranganna (1997).

**Tissue nutrient analysis:** Samples of 5–7 months old leaf were collected during August–October and carefully washed for removing any surface contamination (Srivastava *et al.* 2005). The samples were then oven dried, grounded and digested (Chapman and Pratt 1961). Nutrient content was analysed following standard methods: N (Jackson 1973), P (Hesse 1971), K (Chapman and Pratt 1961), Ca and Mg (Cheng and Bray 1951) and micronutrients (Zasoski and Burau 1977).

**Statistical analysis:** The experiment was implemented following randomised block design with three replications. Data was pooled over the two years and analysed using SPSS version 14.0, with differences between treatments determined by Tukey's Honest Significant Difference (HSD) test at a significance level of  $p \leq 0.05$ .

## RESULTS AND DISCUSSION

**Growth parameters:** Significant differences among the treatments were observed for the growth parameters (Table 1). The maximum plant height, when compared with the minimum value in *Citrus latipes* (Swingle) Yu. Tanaka (296.49 cm), was significantly higher by 19.79% in *Citrus jambhiri* Lush. and 17.61% in *Citrus limonia* (L) Osb. Mean trunk girth was significantly higher by 30.75 and 25.44% in *Citrus jambhiri* Lush. and *Citrus limonia* (L) Osb. as compared to *Citrus karna* Raf. which had the minimum trunk girth (48.84 mm). Canopy spread (east-west) was higher by 26.02 and 21.97% in *Citrus jambhiri* Lush. and *Citrus latipes* (Swingle) Yu. Tanaka as compared to *Poncirus trifoliata* (L.) Raf. which had lowest value (115.82 cm) whereas *Citrus volkameriana* (Ten. and Pasq.) and *Citrus limonia* (L) Osb. recorded 20.74 and 19.21% higher canopy spread (north-south) than *Citrus taiwanica* (Tan. and Shim.) with lowest value (107.18 cm). Similar findings of different influence of rootstocks on the growth parameters of mandarin have also been documented by

Table 1 Effect of different rootstocks on growth traits of Khasi mandarin

Treatments	Trunk girth (mm)	Plant height (cm)	Canopy diameter-East West (cm)	Canopy diameter-North South (cm)
<i>Citrus karna</i> Raf.	48.84 ± 4.65 <sup>d</sup>	311.41 ± 28.88 <sup>bc</sup>	128.89 ± 7.88 <sup>bcd</sup>	124.21 ± 3.79 <sup>ab</sup>
<i>Poncirus trifoliata</i> (L.) Raf.	57.28 ± 1.39 <sup>bc</sup>	319.53 ± 32.02 <sup>abc</sup>	115.82 ± 6.40 <sup>d</sup>	108.21 ± 4.86 <sup>ab</sup>
<i>Citrus jambhiri</i> Lush.	63.87 ± 4.10 <sup>a</sup>	355.17 ± 12.07 <sup>a</sup>	145.96 ± 11.19 <sup>a</sup>	123.10 ± 11.69 <sup>ab</sup>
<i>Citrus limonia</i> (L) Osb.	61.27 ± 6.40 <sup>ab</sup>	348.73 ± 36.24 <sup>ab</sup>	132.69 ± 11.64 <sup>abc</sup>	127.78 ± 5.08 <sup>ab</sup>
<i>Citrus latipes</i> (Swingle) Yu. Tanaka	53.21 ± 1.57 <sup>cd</sup>	296.49 ± 29.52 <sup>c</sup>	141.27 ± 9.51 <sup>ab</sup>	110.90 ± 5.40 <sup>ab</sup>
<i>Citrus taiwanica</i> (Tan. & Shim.)	55.66 ± 2.05 <sup>c</sup>	327.00 ± 25.21 <sup>abc</sup>	123.61 ± 10.32 <sup>cd</sup>	107.18 ± 2.48 <sup>b</sup>
<i>Citrus volkameriana</i> (Ten. & Pasq.)	58.40 ± 2.00 <sup>bc</sup>	342.22 ± 29.34 <sup>ab</sup>	132.66 ± 7.05 <sup>abc</sup>	129.42 ± 5.17 <sup>a</sup>

Values given are mean with ±SD followed by different letters on each column indicate significant difference from each other according to Tukey's test ( $p < 0.05$ ).

Dubey and Singh (2003), Josan and Thatai (2008), Singh *et al.* (2009) and Nasir *et al.* (2011). The superiority in growth parameters shown by *Citrus jambhiri* Lush. and *Citrus limonia* (L) Osb. over other rootstocks may be attributed to better nutrient absorption due to efficient root system of the rootstocks. Gregory *et al.* (2013) and Khan *et al.* (2020) reported that root is the responsible organ for transporting water and nutrients from the soil to over-ground parts of the plants which consequently influenced the growth of the plants. Further, Kumar *et al.* (2017) suggested the impact of the rootstocks on the scion variety could be attributed to the inherent genetic character of the rootstocks.

**Yield parameters:** The rootstocks had a significant impact on the yield parameters (Table 2). About 40.28, 37.99 and 34.75% more fruits was recorded in *Citrus jambhiri* Lush., *Citrus limonia* (L) Osb. and *Citrus volkameriana* (Ten. & Pasq.) which are statistically at par as compared to *Citrus taiwanica* (Tan. & Shim.) with lowest number of fruits per plant (41.02). In comparison to the lowest fruit weight (103.58 gm) recorded in *Poncirus trifoliata* (L.) Raf., it was significantly higher by 27.11% in *Citrus volkameriana* (Ten. & Pasq.) and 24.39% in *Citrus limonia* (L) Osb. Fruit yield varies significantly among different rootstocks, where *Citrus jambhiri* Lush., *Citrus limonia* (L) Osb. and *Citrus volkameriana* (Ten. & Pasq.) which are at par produced the maximum yield and the lowest was recorded in *Poncirus trifoliata* (L.) Raf. with 38.60% less yield as against the mean maximum yield (7.29 kg/tree). No significant variation in fruit length among all treatments however the longest value was observed in *Citrus limonia* (L) Osb. followed by *Citrus volkameriana* (Ten. & Pasq.) and lowest in *Citrus jambhiri* Lush. Fruit width was highest in *Citrus limonia* (L) Osb. which is however at par with *Citrus jambhiri*

Lush. and *Citrus volkameriana* (Ten. & Pasq.) and lowest in *Citrus taiwanica* (Tan. & Shim.) (52.23 cm). Peel weight recorded in *Citrus taiwanica* (Tan. & Shim.) and *Citrus latipes* (Swingle) Yu. Tanaka were statistically at par, which weighted 47.33 and 40.02% more than the lowest value in *Poncirus trifoliata* (L.) Raf. (21.76 g). When compared the nos. of segments recorded in different treatment, *Citrus limonia* (L) Osb. have 44.64% more segments that *Citrus taiwanica* (Tan. & Shim.) (9.33). Although no significant difference in the nos. of seeds was observed among different treatment, *Citrus karna* Raf. recorded 38.51% less number of seed when compared with the maximum value in *Citrus latipes* (Swingle) Yu. Tanaka (21.07). The main focus of an orchardist is maximum yield of good quality fruits for profitable fruit cultivation. The improved yield attributes of Khasi mandarin observed on *Citrus jambhiri* Lush., *Citrus limonia* (L) Osb. and *Citrus volkameriana* (Ten. & Pasq.) was probably due to better vigour and greater canopy volume which provides more fruiting area than other rootstocks (Gora *et al.* 2022). Furthermore, Ghosh *et al.* (2012) suggested sound root system enhances the plant's ability to absorb water and nutrients from the soil, and create variations in leaf photosynthetic rates and the distribution of assimilates from source to sink, as affected by scion-rootstock combinations have contributed to differences in the yield potential of the scion. Our findings conform to those of Carvalho *et al.* (2016) and Kumar *et al.* (2016). In contrast, the lower yield in other rootstocks suggested that this may be due to some inferior properties such as a sparse canopy, poor compatibility, lower water and nutrient uptake, and its subsequent translocation to the scion (Gora *et al.* 2022). The impact of different rootstocks on fruit size and other yield attributing characters of commercial

Table 2 Effect of different rootstocks on yield traits of Khasi mandarin

Treatment	No. of fruit per tree	Fruit weight (gm)	Fruit yield (kg/tree)	Fruit length (cm)	Fruit width (cm)	Peel weight (g)	No. of segment/ fruit	No. of seed
<i>Citrus karna</i> Raf.	49.77 ± 1.20 <sup>b</sup>	117.04 ± 6.03 <sup>bcd</sup>	5.83 ± 4.40 <sup>b</sup>	43.94 ± 1.34 <sup>a</sup>	59.54 ± 1.88 <sup>ab</sup>	22.94 ± 2.29 <sup>b</sup>	11.00 ± 0.29 <sup>b</sup>	12.95 ± 1.62 <sup>b</sup>
<i>Poncirus trifoliata</i> (L.) Raf.	43.18 ± 2.76 <sup>c</sup>	103.58 ± 4.33 <sup>c</sup>	4.47 ± 0.33 <sup>c</sup>	45.94 ± 1.78 <sup>a</sup>	58.92 ± 2.19 <sup>ab</sup>	21.76 ± 2.25 <sup>b</sup>	10.00 ± 0.14 <sup>bc</sup>	13.66 ± 2.16 <sup>b</sup>
<i>Citrus jambhiri</i> Lush.	57.54 ± 1.09 <sup>a</sup>	122.67 ± 6.18 <sup>abc</sup>	7.06 ± 0.29 <sup>a</sup>	42.83 ± 1.70 <sup>a</sup>	60.18 ± 2.33 <sup>a</sup>	25.08 ± 3.49 <sup>b</sup>	10.00 ± 0.50 <sup>bc</sup>	16.30 ± 0.63 <sup>b</sup>
<i>Citrus limonia</i> (L) Osb.	56.60 ± 1.87 <sup>a</sup>	128.85 ± 8.51 <sup>ab</sup>	7.29 ± 0.55 <sup>a</sup>	51.97 ± 1.59 <sup>a</sup>	62.02 ± 3.61 <sup>a</sup>	23.15 ± 1.42 <sup>b</sup>	13.50 ± 0.50 <sup>a</sup>	13.41 ± 0.89 <sup>b</sup>
<i>Citrus latipes</i> (Swingle) Yu. Tanaka	47.25 ± 0.31 <sup>b</sup>	104.93 ± 6.76 <sup>de</sup>	4.96 ± 0.34 <sup>c</sup>	44.44 ± 1.40 <sup>a</sup>	58.51 ± 1.90 <sup>ab</sup>	30.47 ± 1.95 <sup>a</sup>	11.00 ± 0.38 <sup>b</sup>	21.07 ± 1.77 <sup>a</sup>
<i>Citrus taiwanica</i> (Tan. & Shim.)	41.02 ± 1.28 <sup>c</sup>	113.66 ± 5.92 <sup>ode</sup>	4.66 ± 0.34 <sup>c</sup>	43.16 ± 1.45 <sup>a</sup>	52.23 ± 4.42 <sup>b</sup>	22.34 ± 4.48 <sup>b</sup>	9.33 ± 0.58 <sup>c</sup>	16.08 ± 1.96 <sup>b</sup>
<i>Citrus volkameriana</i> (Ten. & Pasq.)	55.28 ± 1.68 <sup>a</sup>	131.66 ± 10.22 <sup>a</sup>	7.29 ± 0.76 <sup>a</sup>	50.07 ± 2.31 <sup>a</sup>	61.09 ± 3.56 <sup>a</sup>	32.06 ± 1.44 <sup>a</sup>	10.00 ± 0.04 <sup>6bc</sup>	14.91 ± 1.26 <sup>b</sup>

Values given are mean with ±SD followed by different letters on each column indicate significant difference from each other according to Tukey's test ( $p < 0.05$ ).

cultivars of citrus were also reported by Tuzcu *et al.* (1992) and Georgiou (2000).

**Biochemical parameters:** Biochemical attributes differed significantly among different treatment as indicated by Table 3. *Citrus limonia* (L) Osb. recorded 40.03% more juice than the lowest value recorded in *Citrus jambhiri* Lush (36.03%). When compared with the minimum TSS (7.44°Brix) recorded in *Poncirus trifoliata* (L.) Raf., it was observed that *Citrus taiwanica* (Tan. & Shim.) and *Citrus volkameriana* (Ten. & Pasq.) had 22.73% more TSS whereas the other rootstocks had intermediate values. *Citrus volkameriana* (Ten. & Pasq.) showed a significantly higher mean total sugar content, exceeding by 35.42% that of *Citrus latipes* (Swingle) Yu. Tanaka with the lowest (5.68%). The reducing sugar content was also significantly greater in *Citrus volkameriana* (Ten. & Pasq.), showing a 37.25% increase compared to *Citrus latipes* (Swingle) Yu. Tanaka, which recorded the lowest value at 3.28%. With respect to ascorbic acid, *Citrus volkameriana* (Ten. & Pasq.) recorded 25.12% more than the lowest value in *Citrus jambhiri* Lush (39.64 mg/100 g). In contrast, *Citrus volkameriana* (Ten. & Pasq.) recorded 35.86% less titratable acidity as against the highest value in *Citrus latipes* (Swingle) Yu. Tanaka (1.92%). According to Forner-Giner *et al.* (2003) and Hussain *et al.* (2013), increased juice content, total soluble solids (TSS), sugar levels, and ascorbic acid, along with reduced acidity, are essential quality characteristics that improve fruit acceptance in both the fresh market and processing sectors. These variations in the biochemical attributes of scion fruits might have been caused by the influenced of rootstocks on the physiological performance of the scion (Shafqat *et al.* 2020). This may be the rationale behind the observed differences in biochemical attributes

among Khasi mandarin plants. The findings of this study were in agreement with previous reports of other workers that biochemical properties of citrus scion cultivars was affected by rootstocks (Georgion 2000, Kumar *et al.* 2016 and Kumar *et al.* 2022).

**Nutrient content of leaf:** Leaf nutrient levels of Khasi mandarin plants were significantly influenced by the rootstocks (Table 4 and Table 5). A significant difference in N accumulation among rootstocks was observed with Khasi mandarin plants on *Citrus jambhiri* Lush accumulated 32.84% more N in their leaves as compared to the minimum N accumulation in *Poncirus trifoliata* (L.) Raf. (2.14%). *Citrus karna* Raf. and *Citrus jambhiri* Lush were at par with each other and accumulated 24.83% more P content than the minimum (0.12%) in *Citrus taiwanica* (Tan. & Shim.). Leaf K content was significantly higher by 20.29% in *Citrus jambhiri* Lush than the minimum value in *Citrus karna* Raf. (1.82%). The leaf Ca content was recorded maximum on *Citrus jambhiri* Lush which is 22.58% more than the minimum value in *Citrus latipes* (Swingle) Yu. Tanaka (1.86%). Magnesium uptake was notably affected by the combination of scion and rootstock. *Citrus limonia* [L] Osb. exhibited a 36.32% higher Mg accumulation compared to the lowest levels found in *Citrus karna* Raf. and *Citrus taiwanica* (Tan. & Shim.) (0.34%). Likewise, rootstock had a significant impact on foliar iron (Fe) concentration, with *Citrus jambhiri* Lush and *Citrus limonia* [L] Osb. showing similar increases of 24.74% and 22.50%, respectively, over the minimum Fe content observed in *Citrus latipes* (Swingle) Yu. Tanaka (187.93 mg/kg). Khasi mandarin plants grown on *Citrus limonia* [L] Osb. and *Citrus volkameriana* (Ten. & Pasq.) accumulated 20.03% and 16.47% more Zn content as against the minimum amount accumulated in

Table 3 Effect of different rootstocks on physico-chemical qualities of Khasi mandarin

Treatment	Juice (%)	TSS (°Brix)	Titratable acidity (%)	Ascorbic acid (mg/100 g)	Total Sugars (%)	Reducing sugar (%)	TSS:Acid ratio
<i>Citrus karna</i> Raf.	46.53 ± 2.33 <sup>ab</sup>	8.06 ± 0.31 <sup>bc</sup>	1.57 ± 0.06 <sup>bc</sup>	44.71 ± 0.75 <sup>b</sup>	7.01 ± 0.16 <sup>cd</sup>	3.73 ± 0.10 <sup>c</sup>	5.14
<i>Poncirus trifoliata</i> (L.) Raf.	36.10 ± 3.42 <sup>b</sup>	7.44 ± 0.38 <sup>d</sup>	1.83 ± 0.01 <sup>a</sup>	48.35 ± 1.43 <sup>a</sup>	6.57 ± 0.24 <sup>d</sup>	3.43 ± 0.14 <sup>cd</sup>	4.07
<i>Citrus jambhiri</i> Lush.	36.03 ± 1.61 <sup>b</sup>	8.56 ± 0.26 <sup>b</sup>	1.66 ± 0.06 <sup>b</sup>	39.64 ± 1.44 <sup>c</sup>	6.81 ± 0.04 <sup>cd</sup>	3.66 ± 0.12 <sup>c</sup>	5.17
<i>Citrus limonia</i> (L) Osb.	50.45 ± 1.39 <sup>a</sup>	8.17 ± 0.40 <sup>bc</sup>	1.54 ± 0.05 <sup>c</sup>	43.57 ± 1.86 <sup>bc</sup>	7.11 ± 0.07 <sup>bc</sup>	4.08 ± 0.19 <sup>b</sup>	5.31
<i>Citrus latipes</i> (Swingle) Yu. Tanaka	38.34 ± 2.54 <sup>b</sup>	7.98 ± 0.18 <sup>c</sup>	1.92 ± 0.08 <sup>a</sup>	45.49 ± 1.47 <sup>b</sup>	5.68 ± 0.63 <sup>e</sup>	3.28 ± 0.14 <sup>d</sup>	4.17
<i>Citrus taiwanica</i> (Tan. & Shim.)	41.89 ± 1.30 <sup>ab</sup>	9.13 ± 0.45 <sup>a</sup>	1.39 ± 0.01 <sup>d</sup>	41.35 ± 2.66 <sup>cd</sup>	7.47 ± 0.34 <sup>ab</sup>	4.08 ± 0.19 <sup>b</sup>	6.60
<i>Citrus volkameriana</i> (Ten. & Pasq.)	46.38 ± 1.25 <sup>ab</sup>	9.13 ± 0.57 <sup>a</sup>	1.23 ± 0.10 <sup>e</sup>	49.60 ± 2.16 <sup>a</sup>	7.69 ± 0.17 <sup>a</sup>	4.50 ± 0.16 <sup>a</sup>	7.56

Values given are mean with ±SD followed by different letters on each column indicate significant difference from each other according to Tukey's test ( $p < 0.05$ ).

Table 4 Effect of different rootstocks on leaf macro-nutrients content of Khasi mandarin

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
<i>Citrus karna</i> Raf.	2.73 ± 0.07 <sup>ab</sup>	0.15 ± 0.01 <sup>a</sup>	1.82 ± 0.05 <sup>c</sup>	2.20 ± 0.06 <sup>ab</sup>	0.34 ± 0.01 <sup>c</sup>
<i>Poncirus trifoliata</i> (L.) Raf.	2.14 ± 0.04 <sup>c</sup>	0.13 ± 0.01 <sup>b</sup>	1.90 ± 0.07 <sup>bc</sup>	2.05 ± 0.04 <sup>de</sup>	0.35 ± 0.03 <sup>e</sup>
<i>Citrus jambhiri</i> Lush.	2.85 ± 0.06 <sup>a</sup>	0.15 ± 0.01 <sup>a</sup>	2.19 ± 0.14 <sup>a</sup>	2.28 ± 0.05 <sup>a</sup>	0.42 ± 0.02 <sup>b</sup>
<i>Citrus limonia</i> (L) Osb.	2.54 ± 0.11 <sup>c</sup>	0.13 ± 0.01 <sup>ab</sup>	2.05 ± 0.11 <sup>ab</sup>	2.15 ± 0.09 <sup>bc</sup>	0.46 ± 0.01 <sup>a</sup>
<i>Citrus latipes</i> (Swingle) Yu. Tanaka	2.78 ± 0.01 <sup>ab</sup>	0.14 ± 0.01 <sup>ab</sup>	1.94 ± 0.04 <sup>bc</sup>	1.86 ± 0.06 <sup>f</sup>	0.35 ± 0.01 <sup>c</sup>
<i>Citrus taiwanica</i> (Tan. & Shim.)	2.42 ± 0.05 <sup>d</sup>	0.12 ± 0.01 <sup>b</sup>	1.86 ± 0.11 <sup>bc</sup>	1.97 ± 0.04 <sup>e</sup>	0.34 ± 0.01 <sup>c</sup>
<i>Citrus volkameriana</i> (Ten. & Pasq.)	2.72 ± 0.08 <sup>b</sup>	0.14 ± 0.02 <sup>ab</sup>	1.97 ± 0.13 <sup>bc</sup>	2.10 ± 0.01 <sup>cd</sup>	0.43 ± 0.02 <sup>b</sup>

Values given are mean with ±SD followed by different letters on each column indicate significant difference from each other according to Tukey's test ( $p < 0.05$ ).

Table 5 Effect of different rootstocks on leaf micro-nutrients content of Khasi mandarin

Treatment	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)
<i>Citrus karna</i> Raf.	213.40 ± 5.39 <sup>bc</sup>	20.04 ± 0.51 <sup>cd</sup>	2.56 ± 0.06 <sup>c</sup>	75.00 ± 1.89 <sup>cd</sup>
<i>Poncirus trifoliata</i> (L.) Raf.	189.96 ± 3.98 <sup>d</sup>	19.08 ± 0.57 <sup>d</sup>	2.35 ± 0.05 <sup>d</sup>	76.28 ± 1.60 <sup>bc</sup>
<i>Citrus jambhiri</i> Lush.	234.41 ± 4.76 <sup>a</sup>	21.91 ± 0.46 <sup>ab</sup>	2.74 ± 0.06 <sup>b</sup>	79.44 ± 1.60 <sup>b</sup>
<i>Citrus limonia</i> (L) Osb.	230.20 ± 5.81 <sup>a</sup>	22.90 ± 0.97 <sup>a</sup>	2.94 ± 0.12 <sup>a</sup>	89.53 ± 3.80 <sup>a</sup>
<i>Citrus latipes</i> (Swingle) Yu. Tanaka	187.93 ± 5.57 <sup>d</sup>	19.99 ± 0.08 <sup>cd</sup>	2.50 ± 0.01 <sup>c</sup>	71.58 ± 0.30 <sup>d</sup>
<i>Citrus taiwanica</i> (Tan. & Shim.)	207.44 ± 4.19 <sup>c</sup>	20.95 ± 0.42 <sup>bc</sup>	2.00 ± 0.06 <sup>e</sup>	76.62 ± 2.27 <sup>bc</sup>
<i>Citrus volkameriana</i> (Ten. & Pasq.)	218.79 ± 0.92 <sup>b</sup>	22.22 ± 0.56 <sup>a</sup>	2.77 ± 0.06 <sup>b</sup>	91.53 ± 1.86 <sup>a</sup>

Values given are mean with ±SD followed by different letters on each column indicate significant difference from each other according to Tukey's test ( $p < 0.05$ ).

*Poncirus trifoliata* [L.] Raf. (19.08 mg/kg). Accumulation of Cu in Khasi mandarin leaves was significantly higher by 47.18% in *Citrus limonia* [L] Osb. than the minimum in *Citrus taiwanica* (Tan. & Shim.) (2.00 mg/kg). Similarly, when compared with the lowest foliar Mn content (71.58 mg/kg) recorded in *Citrus latipes* (Swingle) Yu. Tanaka, accumulation of Mn in the leaves of Khasi mandarin was higher by 27.87% in *Citrus volkameriana* (Ten. & Pasq.) and 25.09% in *Citrus limonia* [L] Osb. The varying rates of nutrient accumulation in the leaves of scion plants due to the use of different rootstocks have been documented in several crops, including Fairchild mandarin (Fallahi and Rodney 1992), lemon (Dubey and Sharma 2016), Nagpur mandarin (Marathe *et al.* 2006, Sau *et al.* 2018), and Sikkim mandarin (Kumar *et al.* 2017). The higher nutrient accumulation observed in Khasi mandarin leaves grafted onto *Citrus jambhiri* Lush., *Citrus limonia* [L] Osb., and *Citrus volkameriana* (Ten. & Pasq.) may be attributed to the rootstocks' inherent differences in nutrient uptake efficiency and the scion's ability to utilize those nutrients, both of which are primarily determined by the genetic traits of the specific rootstock-scion combination (Sharma *et al.* 2016). Additionally, variations in leaf nutrient content could also result from differences in the hydraulic conductance capacity of the rootstocks, which is positively associated with nutrient accumulation (Cohen and Naor 2002). Another possible explanation for the increased nutrient accumulation in scions grafted onto different rootstocks

is the presence of an extensive root system, which likely allowed these rootstocks to explore a greater soil volume, thereby improving nutrient absorption (Kumar *et al.* 2018, Hayat *et al.* 2019).

In conclusion, different rootstocks exhibit notable differences in growth performance, yield, fruit quality, and their ability to absorb nutrients from the soil. *Citrus jambhiri* Lush., *Citrus limonia* (L) Osb. and *Citrus volkameriana* (Ten. & Pasq.) proved to be a superior rootstocks for most of the studied parameters. Thus, *Citrus jambhiri* Lush., *Citrus limonia* (L) Osb. and *Citrus volkameriana* (Ten. & Pasq.) may be recommended as suitable rootstock for Khasi mandarins.

#### ACKNOWLEDGEMENT

The authors are grateful to the Director ICAR Research Complex for NEH Region, Umiam, Meghalaya for providing research financial support and laboratory facilities during this study under the institute project IXX13442.

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