**IMPROVING FRUIT QUALITY AND YIELD IN DAISY MANDARIN (*Citrus reticulata*) BY FOLIAR APPLICATION OF MANGANESE AND IRON**

**Abstract**

In a study at Guru Kashi University, Talwandi Sabo, Punjab, evaluated the effects of foliar-applied manganese (Mn) and iron (Fe) on () Daisy mandarin (*Citrus reticulata*) fruit characteristics and quality in a six-year-old orchard budded on Jatti Khatti (*Citrus jambhiri* *Lush*) rootstock. Manganese sulphate (0.1%, 0.2%, 0.3%) and ferrous sulphate (0.1%, 0.2%, 0.3%) were applied individually and in combination, using a Randomized Block Design with sixteen treatments, four replications, and sixty-four treatment combinations. The combination of 0.3% MnSO₄ + 0.2% FeSO₄ significantly improved fruit length (138.0 mm), juice content (39.18%), vitamin C (39.97 mg/100g), and fruit firmness (14.9 kg/cm²) compared to the control. The highest TSS (12.75 °Brix) was observed with 0.2% MnSO₄, however, 0.3% MnSO₄ + 0.3% FeSO₄ maximized fruit weight (156.87 g), fruit number (480.5), and yield (75.37 kg/plant).

**Keywords:** Foliar application, Manganese sulphate, Ferrous sulphate, Fruit quality, Yield, Vitamin C, TSS.

**Introduction**

Citrus crops are pivotal to global horticulture, contributing significantly to agricultural production, nutritional health, and economic trade. Annually, over 150 million metric tons of citrus fruits, including oranges, mandarins, lemons, limes, and grapefruits, are produced across 10.2 million hectares worldwide, with China, Brazil, India, and Mexico lead as top producers (Alonso *et al.,* 2023; Tariq *et al.,* 2024; FAO, 2023). In India, citrus cultivation spans 1.086 million hectares, yielding 14.26 million tons, with mandarins alone accounting for 6.35 million tons in 2023 (Keelery, 2023). Punjab, a key citrus-producing region, cultivates 52,836 hectares, primarily of Kinnow mandarins, with an annual production of 1.05 million tons and an exceptional productivity of 42.4 tons/ha (PAU Ludhiana, 2023; Anonymous, 2021).

Citrus fruits are prized for their nutritional profile, which is rich in vitamin C, dietary fibre, and bioactive compounds such as flavonoids and carotenoids, offering antioxidant, cardioprotective, and anti-inflammatory benefits (Sharma *et al.,* 2024; Kaur *et al.,* 2024a). The Daisy mandarin (*Citrus reticulata*), a hybrid of Fortune and Fremont mandarins, is particularly valued for its vibrant deep orange rind, early maturity, and balanced sweetness-acidity profile, making it a premium cultivar in domestic and international markets (Gill *et al.,* 2017; Kaur *et* *al.,* 2024a).

Iron supports chlorophyll synthesis and photosynthesis, and its deficiency leads to chlorosis, reducing photosynthetic efficiency and fruit size (Tariq *et al.,* 2024). Manganese aids enzymatic processes, while magnesium is central to chlorophyll structure, (Sharma *et al.,* 2024; Anwar *et al.,* 2022). Foliar application of micronutrients, particularly Fe and Mn, has shown promise in enhancing fruit weight, sugar accumulation, and overall quality in citrus (Kaur *et al.,* 2024a).

This study aims to evaluate the effects of foliar-applied manganese and iron on the fruit quality and yield of Daisy mandarin in Punjab, hypothesizing that optimized micronutrient combinations will significantly enhance quality () parameters.

**Materials and Methods**

The study was conducted in 2024 at Guru Kashi University, Talwandi Sabo, Punjab, India, characterized by a subtropical climate. Sixty-four healthy, six-year-old Daisy mandarin (*Citrus reticulata*) trees, budded on Jatti Khatti (*Citrus jambhiri Lush*) rootstock, were selected for their uniformity. The experiment employed a Randomized Block Design (RBD) with 16 treatments inclusive of control, replicated four times, making 64 treatment combinations. Treatments comprised a water-spray control, solo applications of manganese sulphate at 0.1% , 0.2% , and 0.3%, and ferrous sulphate at 0.1%, 0.2% , and 0.3%, and their treatment combinations: 0.1% MnSO₄ + 0.1% FeSO₄, 0.1% MnSO₄ + 0.2% FeSO₄ , 0.1% MnSO₄ + 0.3% FeSO₄, 0.2% MnSO₄ + 0.1% FeSO₄, 0.2% MnSO₄ + 0.2% FeSO₄, 0.2% MnSO₄ + 0.3% FeSO₄, 0.3% MnSO₄ + 0.1% FeSO₄, 0.3% MnSO₄ + 0.2% FeSO₄, and 0.3% MnSO₄ + 0.3% FeSO₄. Foliar sprays were administered twice during the growing season using a high-pressure sprayer to ensure complete canopy coverage. Fruit diameter was measured at the equatorial plane using a digital Vernier calliper (accuracy: 0.01 mm), ensuring perpendicular alignment without fruit compression (Tariq, M., *et al.,* 2024). Juice content (%) was determined by weighing fruits and extracted juice on an electronic balance (accuracy: 0.01 g), calculated as: (Weight of Juice Extracted / Total Fruit Weight) × 100 (Kaur, N., *et al.*, 2024a). Vitamin C content (mg/100 g) was quantified via the 2,6-dichlorophenolindophenol (DCPIP) titration method, (Gullo, G., *et al.,* 2023). Fruit firmness (kg/cm²) was evaluated using a penetrometer (Lado, J., *et al.,*2024*).* Total soluble solids (TSS, °Brix) were measured with a digital refractometer (Sharma, R., *et al.,* 2024). Titratable acidity (%) was assessed by titrating 5–10 ml of juice with 0.1 M NaOH and phenolphthalein indicator (Kaur, N., *et al.,* 2024a). The number of fruits per plant and yield per plant (kg) were determined by harvesting all fruits at full maturity in a single picking, counted fruits, and weighed the total yield per tree. Statistical analysis was done as per the Gomez, K. A. and Gomez, A. A., 1983.

**Results and Discussion**

**Fruit Diameter (mm):** Significant variations in Daisy mandarin fruit diameter were observed, with the highest fruit length and width recorded in T14 0.3% MnSO₄ + 0.2% FeSO₄(138 mm) and T15 0.3% MnSO₄ + 0.3% FeSO₄ (136.6 mm), respectively, while the untreated control (T0) showed the lowest length (101.4 mm) and width (119.70 mm). Treatments T5 0.2% FeSO4 (114.40 mm) and T6 0.3% FeSO4 (116.80 mm) had moderate, statistically similar fruit lengths, while T10 0.2% MnSO4 + 0.1% FeSO4 (141.10 mm) and T11 0.2% MnSO4 + 0.2% FeSO4 (114.40 mm) exhibited improved widths compared to T0. The combined application of Mn and Fe enhanced fruit growth.

**4.1. Table 1. Effect of Different Treatments and their combinations on Fruit diameter (Length, width)**

|  |  |  |
| --- | --- | --- |
| **Treatments** | **Fruit Length in mm** | **Fruit width in mm** |
| T0 Control | 101.40 | 119.70 |
| T1 (0.1% Manganese sulphate) | 105.30 | 120.10 |
| T2 (0.2% Manganese sulphate) | 106.90 | 121.80 |
| T3 (0.3% Manganese sulphate) | 110.30 | 122.90 |
| T4 (0.1% Ferrous sulphate) | 110.40 | 124.10 |
| T5 (0.2% Ferrous sulphate) | 114.40 | 129.60 |
| T6 (0.3% Ferrous sulphate) | 116.80 | 130.50 |
| T7 (0.1% Manganese sulphate + 0.1% Ferrous sulphate) | 117.60 | 135.70 |
| T8 (0.1% Manganese sulphate + 0.2% Ferrous sulphate) | 119.50 | 137.10 |
| T9 (0.1% Manganese sulphate + 0.3% Ferrous sulphate) | 120.70 | 139.10 |
| T10 (0.2% Manganese sulphate + 0.1% Ferrous sulphate) | 125.30 | 141.10 |
| T11 (0.2% Manganese sulphate+ 0.2% Ferrous sulphate) | 128.20 | 141.40 |
| T12 (0.2% Manganese sulphate + 0.3% Ferrous sulphate) | 132.90 | 142.00 |
| T13 (0.3% Manganese sulphate + 0.1% Ferrous sulphate) | 133.90 | 143.45 |
| T14 (0.3% Manganese sulphate + 0.2% Ferrous sulphate) | 138.00 | 148.40 |
| T15 (0.3% Manganese sulphate + 0.3% Ferrous sulphate) | 136.60 | 149.90 |
| C.D. at 5% | 1.664 | 1.382 |

**Juice Per cent (%):** The foliar application under T14 0.3% MnSO₄ + 0.2% FeSO₄ (39.18%) yielded the highest juice () per cent in Daisy mandarin fruits, significantly surpassing that of T0 Control (26.06%). Treatments T15 0.3% MnSO₄ + 0.3% FeSO₄(33.58%), T13 0.3% MnSO4 + 0.1% FeSO4 (31.76%) and T12 0.2% MnSO4 + 0.3% FeSO4 (31.47%) were statistically comparable to T14 0.3% MnSO4 + 0.2% FeSO4 (39.18%),

**Vitamin C Content (mg)**: Foliar application of manganese and iron significantly boosted vitamin C content in Daisy mandarin fruits, with the highest concentration in T14 0.3% MnSO₄ + 0.2% FeSO₄ (39.97mg), closely followed by T15 0.3% MnSO₄ + 0.3% FeSO₄(39.1mg) and T13 0.3% MnSO4 + 0.1% FeSO4 (38.52 mg), which were statistically at par. The lowest vitamin C level 23.65 mg was recorded in the control.

**Fruit Firmness (Kg/cm2):** Foliar application of manganese and iron significantly enhanced Daisy mandarin fruit firmness, with the highest value in T14 0.3% MnSO₄ + 0.2% FeSO₄(14.9 Kg/cm2), followed closely by T2 0.2% MnSO4 (14.90 Kg/cm2) and T12 0.2% MnSO4 + 0.3% FeSO4 (13.90 Kg/cm2). This shows that combined micronutrient sprays improve fruit firmness and potentially extends its shelf life.

**4.2. Table 2. Effect of Different Treatments and their combinations on Juice Percentage, Vitamin C content and Fruit firmness**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **Juice Percentage (%)** | **Vitamin C content (mg)** | **Fruit Firmness (Kg/cm2)** |
| T0 Control | 26.06 | 23.65 | 7.70 |
| T1 (0.1% Manganese sulphate) | 27.85 | 25.20 | 8.50 |
| T2 (0.2% Manganese sulphate) | 27.86 | 26.95 | 14.90 |
| T3 (0.3% Manganese sulphate) | 28.41 | 27.85 | 9.80 |
| T4 (0.1% Ferrous sulphate) | 29.17 | 28.67 | 10.30 |
| T5 (0.2% Ferrous sulphate) | 29.24 | 29.72 | 10.80 |
| T6 (0.3% Ferrous sulphate) | 29.54 | 30.00 | 11.00 |
| T7 (0.1% Manganese sulphate + 0.1% Ferrous sulphate) | 29.71 | 31.10 | 11.30 |
| T8 (0.1% Manganese sulphate + 0.2% Ferrous sulphate) | 29.76 | 31.67 | 11.60 |
| T9 (0.1% Manganese sulphate + 0.3% Ferrous sulphate) | 29.83 | 32.47 | 13.10 |
| T10 (0.2% Manganese sulphate + 0.1% Ferrous sulphate) | 30.03 | 33.80 | 12.80 |
| T11 (0.2% Manganese sulphate+ 0.2% Ferrous sulphate) | 30.88 | 34.75 | 13.30 |
| T12 (0.2% Manganese sulphate + 0.3% Ferrous sulphate) | 31.47 | 35.70 | 13.90 |
| T13 (0.3% Manganese sulphate + 0.1% Ferrous sulphate) | 31.76 | 38.52 | 13.70 |
| T14 (0.3% Manganese sulphate +0.2% Ferrous sulphate) | 39.18 | 39.97 | 14.90 |
| T15 (0.3% Manganese sulphate +0.3% Ferrous sulphate) | 33.58 | 39.10 | 9.10 |
| C.D. at 5% | 8.0957 | 0.73 | 0.289 |

**Total Soluble Solids** **(°Brix):** The perusal of data in Table 3 and Fig. 1 showed significant variation in TSS levels across treatments, with T2 0.2% MnSO4 (12.75°Brix) recording the highest TSS.

**Acidity Per cent:** The study showed slight variations in fruit acidity across treatments, with the highest value (0.54%) in T8 0.1% MnSO4 + 0.2% FeSO4 and T14 0.3% MnSO₄ + 0.2% FeSO₄, indicating that specific manganese and iron combinations help maintain acidity. The lowest acidity was observed in T2 0.2% MnSO4 (0.38%), which also had the highest sugar content, reflecting the typical inverse relationship between acidity and sweetness during ripening.

**TSS: Acid Ratio:** The TSS: acid ratio, crucial for fruit flavour, peaked at T2 0.2% MnSO4 (33.55), indicating high sugar and low acidity, while the lowest ratio was recorded in T8 0.1% MnSO4 + 0.2% FeSO4 (19.01) due to higher acidity and lower sugar.

**4.3. Table 3. Effect of Different treatments and their combinations on Total Soluble Solids, Acidity per cent and TSS: Acid ratio**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **TSS in °Brix** | **Acidity percentage (%)** | **TSS: Acid ratio** |
| T0 Control | 10.50 | 0.39 | 20.86 |
| T1 (0.1% Manganese sulphate) | 10.47 | 0.42 | 22.72 |
| T2 (0.2% Manganese sulphate) | 12.75 | 0.38 | 33.55 |
| T3 (0.3% Manganese sulphate) | 9.65 | 0.40 | 22.34 |
| T4 (0.1% Ferrous sulphate) | 9.95 | 0.40 | 22.39 |
| T5 (0.2% Ferrous sulphate) | 10.22 | 0.42 | 22.44 |
| T6 (0.3% Ferrous sulphate) | 9.42 | 0.39 | 24.15 |
| T7 (0.1% Manganese sulphate + 0.1% Ferrous sulphate) | 10.65 | 0.44 | 22.88 |
| T8 (0.1% Manganese sulphate + 0.2% Ferrous sulphate) | 10.27 | 0.54 | 19.01 |
| T9 (0.1% Manganese sulphate + 0.3% Ferrous sulphate) | 10.90 | 0.48 | 24.20 |
| T10 (0.2% Manganese sulphate + 0.1% Ferrous sulphate) | 11.20 | 0.50 | 24.33 |
| T11 (0.2% Manganese sulphate+ 0.2% Ferrous sulphate) | 11.67 | 0.51 | 24.78 |
| T12 (0.2% Manganese sulphate + 0.3% Ferrous sulphate) | 11.42 | 0.51 | 24.87 |
| T13 (0.3% Manganese sulphate + 0.1% Ferrous sulphate) | 11.62 | 0.52 | 24.92 |
| T14 (0.3% Manganese sulphate +0.2% Ferrous sulphate) | 11.12 | 0.54 | 20.59 |
| T15 (0.3% Manganese sulphate +0.3% Ferrous sulphate) | 9.60 | 0.46 | 24.12 |
| C.D. at 5% | 0.916 | 0.013 | 3.0533 |

**Fruit Weight (g):** T15 0.3% MnSO₄ + 0.3% FeSO₄ yielded the highest Daisy mandarin fruit weight (156.87 g), closely followed by T14 0.3% MnSO₄ + 0.2% FeSO₄ (153.75 g), while the control (T0) recorded the lowest (106.62 g). Treatments T15 0.3% MnSO₄ + 0.3% FeSO₄ (156.87 g) and T14 0.3% MnSO₄ + 0.2% FeSO₄ (153.75 g) were statistically at par, highlighting the benefit of higher nutrient concentrations for fruit growth.

**Average Number of Fruits per Tree:** Foliar application of manganese and ferrous sulphate increased fruit count in Daisy mandarin trees, with T15 0.3% MnSO₄ + 0.3% FeSO₄ (480.5) yielding the highest number of fruits and T14 0.3% MnSO₄ + 0.2% FeSO₄ (474.75) close to T15 0.3% MnSO₄ + 0.3% FeSO₄ (480.5). The control (T0) (373.5), without nutrients, had the lowest count, highlighting the impact of nutrient deficiency on production.

**Yield per plant (Kg):** Fruit yield peaked in T15 0.3% MnSO₄ + 0.3% FeSO₄ (75.37 kg/tree), with T14 0.3% MnSO₄ + 0.2% FeSO₄ (72.99 kg/tree) nearly equivalent, while the control (T0) recorded the lowest yield (39.82 kg/tree). These results are as reported by **Sidhu (1988)** indicating that nutrient treatments enhance tree vigour, photosynthesis and boosts yield.

**4.4. Table 4. Effect of Different treatments and their combinations on Fruit weight, Average number of fruits per tree and Fruit Yield of Daisy mandarin**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **Fruit Weight in g** | **Average number of fruits per tree** | **Yield per plant (kg/tree)** |
| T0 Control | 106.62 | 373.50 | 39.82 |
| T1 (0.1% Manganese sulphate) | 131.37 | 380.50 | 49.98 |
| T2 (0.2% Manganese sulphate) | 131.62 | 386.75 | 50.90 |
| T3 (0.3% Manganese sulphate) | 131.62 | 392.50 | 51.66 |
| T4 (0.1% Ferrous sulphate) | 133.25 | 399.00 | 53.16 |
| T5 (0.2% Ferrous sulphate) | 137.50 | 407.50 | 56.03 |
| T6 (0.3% Ferrous sulphate) | 139.12 | 415.25 | 57.76 |
| T7 (0.1% Manganese sulphate + 0.1% Ferrous sulphate) | 139.25 | 422.00 | 58.76 |
| T8 (0.1% Manganese sulphate + 0.2% Ferrous sulphate) | 140.12 | 429.75 | 60.21 |
| T9 (0.1% Manganese sulphate + 0.3% Ferrous sulphate) | 141.00 | 438.00 | 61.75 |
| T10 (0.2% Manganese sulphate + 0.1% Ferrous sulphate) | 142.00 | 444.75 | 63.15 |
| T11 (0.2% Manganese sulphate+ 0.2% Ferrous sulphate) | 145.37 | 451.25 | 65.59 |
| T12 (0.2% Manganese sulphate + 0.3% Ferrous sulphate) | 148.37 | 459.75 | 68.21 |
| T13 (0.3% Manganese sulphate + 0.1% Ferrous sulphate) | 153.00 | 466.75 | 71.41 |
| T14 (0.3% Manganese sulphate +0.2% Ferrous sulphate) | 153.75 | 474.75 | 72.99 |
| T15 (0.3% Manganese sulphate +0.3% Ferrous sulphate) | 156.87 | 480.50 | 75.37 |
| C.D. at 5% | 2.542 | 1.736 | 15.962 |

Foliar application of T14 0.3% MnSO₄ + 0.2% FeSO₄ significantly enhanced Daisy mandarin fruit quality, achieving the highest juice content, vitamin C, and fruit firmness, with results comparable to other high-performing treatments like T15 0.3% MnSO₄ + 0.3% FeSO₄. Lower values were observed in the control, while synergistic Mn and Fe effects boosted nutritional quality, aligning with prior studies (Anitha *et al.,* 2022; Sharma *et al.,* 2024). The highest TSS and TSS: acid ratio were recorded in T2 0.2% MnSO4, enhancing sugar accumulation and flavour (Tariq *et al.,* 2007), while the lowest TSS in T15 0.3% MnSO₄ + 0.3% FeSO₄ suggests excessive micronutrients may impair carbohydrate synthesis (Dhaliwal *et al.,* 2023). The highest fruit weight, number of fruits per plant, and yield per plant were recorded with T15 0.3% MnSO₄ + 0.3% FeSO₄ (Pawar *et al.,* 2019). The control treatment (T0) with water sprays showed the lowest values for fruit length, juice content, vitamin C, fruit weight, and yield, confirming manganese and iron deficiencies in the loamy soil (pH 7.86, 0.47% organic matter) that limited citrus growth and quality, as noted by Obreza *et al.*, (2024). Foliar application under T14 0.3% MnSO₄ + 0.2% FeSO₄ significantly enhanced fruit length, juice content, vitamin C, and firmness, while T15 0.3% MnSO₄ + 0.3% FeSO₄ maximized fruit weight, fruit number, and yield, with T2 0.2% MnSO4 yielding the highest TSS and other treatments showing comparable improvements.

**Conclusion**

Treatment T15 yielding the highest fruit weight, fruit count, yield, and fruit width, while T14 0.3% MnSO₄ + 0.2% FeSO₄ enhanced fruit length, firmness, juice content, and vitamin C. Treatment T2 0.2% MnSO4 achieved the highest TSS and TSS: acid ratio, demonstrating that balanced Mn and Fe applications optimize fruit development, sweetness, and productivity in subtropical conditions.

**References**

Alonso, J., et al. (2023). Global citrus production trends. Journal of Horticultural Science, 45(3), 123–134.

Anonymous. (2021). *Package of Practices for Fruit Crops* (pp. 1–2). Ludhiana, Punjab: Punjab Agricultural University.

Anwar, S.; Ashraf, M.Y.; Saleem, M.; Shafiq, F.; Khan, N.; Khan, R.A.; Farid, G.; Ashraf, M. Integrated hormonal and nutrient management promote fruit retention and quality traits of Citrus reticulata. *J. Plant Nutr.* **2022**, *46*, 83–100.

FAO. (2023). Food and Agriculture Organization of the United Nations [Internet]. Available from: <http://www.fao.org/faostat/en/#data> [Accessed: June 2, 2023].

Gill, M.S., Gill, P.P.S., Brar, J.S. and Khehra, S. (2017). Daisy Mandarin performance in the subtropics of northwest India on three distinct rootstocks. *Conservation of the Environment and Ecology*, 23, 177–183.

Gomez, K. A., & Gomez, A. A. (1983). *Statistical Procedures for Agricultural Research*. John Wiley & Sons.

Gullo, G., et al. (2023). Fruit quality assessment based on mineral elements and juice properties in nine citrus cultivars. Frontiers in Plant Science, 14, 1032456.

Kaur, N., et al. (2024a). Daisy mandarin: Agronomic and nutritional traits. HortScience, 59(6), 789–797.

Lado, J., et al. (2024). Key determinants of citrus fruit quality: Metabolites and main changes during maturation. Scientia Horticulturae, 319, 112134.

Sharma, R., et al. (2024). Nutritional benefits of citrus flavonoids. Journal of Food Biochemistry, 46(1), e13987.

Tariq, M., Sharif, M., Shah, Z., and Khan, R. (2007). Effect of foliar application of micronutrients on the yield and quality of sweet orange (*Citrus sinensis* L.). *Pakistan Journal of Biological Sciences*, 10(11), 1823–1828.

Tariq, M., et al. (2024). Micronutrient management in citrus crops. Agricultural Reviews, 39(2), 87–95.