



Improving Fruit Quality and Yield in Daisy Mandarin Cultivar by Foliar Application of Manganese and Iron

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In a study at Guru Kashi University, Talwandi Sabo, Punjab, evaluated the effects of foliar-applied manganese (Mn) and iron (Fe) on the Daisy mandarin cultivar. 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% $MnSO_4$ + 0.2% $FeSO_4$ 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% $MnSO_4$, however, 0.3% $MnSO_4$ + 0.3% $FeSO_4$ maximized fruit weight (156.87 g), fruit number (480.5), and yield (75.37 kg/plant).

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1. INTRODUCTION

Citrus crops are pivotal to global horticulture, contributing significantly to horticultural 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. In India, citrus cultivation spans 1.086 million hectares, yielding 14.26 million tons, with mandarins alone accounting for 6.35 million tons during 2023 (Kaur et al., 2025; El-Giousy et al., 2021). 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 20.1 tons per hectare.

Citrus fruits are prized for their nutritional profile, having vitamin C, dietary fibre, and bioactive compounds such as flavonoids and carotenoids, offering antioxidant, cardioprotective, and anti-inflammatory benefits. The Daisy mandarin cultivar, a hybrid of Fortune and Fremont mandarins, is particularly valued for its vibrant, deep orange rind, early maturity, and balanced sweetness-to-acidity profile, making it a premium cultivar in both domestic and international markets (Kaur et al., 2024; Moale et al., 2021).

Iron supports chlorophyll synthesis and photosynthesis, and its deficiency leads to chlorosis, reducing photosynthetic efficiency and fruit size. Manganese aids enzymatic processes, while magnesium is central to chlorophyll structure. Foliar application of micronutrients, particularly Fe and Mn, has shown promise in enhancing fruit weight, sugar accumulation, and overall quality in citrus.

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 and yield parameters.

2. MATERIALS AND METHODS

The study was conducted during 2024 at Guru Kashi University, Talwandi Sabo, Punjab, India, (30.9666°N, 75.0871°E, altitude: 242 m), characterized by a subtropical climate. Sixty-four

healthy, six-year-old Daisy mandarin cultivar trees, budded on Jatti Khatti (*Citrus jambhiri Lush*) rootstock, were selected for their uniformity. The orchard was managed following standard package and practices for citrus cultivation in Punjab, including drip irrigation scheduled biweekly to maintain soil moisture at 60–70% field capacity, annual pruning to remove dead or diseased branches and promote canopy aeration, and integrated pest management with applications of neem-based biopesticides.

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% $MnSO_4$ + 0.1% $FeSO_4$, 0.1% $MnSO_4$ + 0.2% $FeSO_4$, 0.1% $MnSO_4$ + 0.3% $FeSO_4$, 0.2% $MnSO_4$ + 0.1% $FeSO_4$, 0.2% $MnSO_4$ + 0.2% $FeSO_4$, 0.2% $MnSO_4$ + 0.3% $FeSO_4$, 0.3% $MnSO_4$ + 0.1% $FeSO_4$, 0.3% $MnSO_4$ + 0.2% $FeSO_4$, and 0.3% $MnSO_4$ + 0.3% $FeSO_4$. 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. Vitamin C content (mg/100 g) was quantified via the 2,6-dichlorophenolindophenol (DCPIP) titration method. Fruit firmness (kg/cm²) was evaluated using a penetrometer. Total soluble solids (TSS, °Brix) were measured with a digital refractometer. Titratable acidity (%) was assessed by titrating 5–10 ml of juice with 0.1 M NaOH and phenolphthalein indicator. 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.

3. 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) Resulted in 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 due to their synergistic roles in critical physiological and biochemical processes. Manganese and iron are essential micronutrients that support plant metabolism, particularly in photosynthesis, enzyme activation, and nutrient assimilation, which directly influence fruit development.

Juice Per cent (%): Application of 0.3% MnSO₄ + 0.2% FeSO₄ yielded the highest juice (39.18%) in Daisy mandarin fruits, significantly surpassing that of T₀ Control (26.06%).

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 39.97mg by T₁₅ (39.1mg) and T₁₃ (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.

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 resulted in light variations in fruit acidity across treatments, with the highest value (0.54%) in (T₁₄) 0.3% MnSO₄ + 0.2% FeSO₄ and (T₁₅) 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 (Laane, 2018; İköz et al., 2024).

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, which is optimal for enhancing sweetness and overall palatability due to the effective balance of manganese promoting sugar accumulation while minimizing acidity while the lowest ratio was recorded in T₈ 0.1% MnSO₄ + 0.2% FeSO₄ (19.01).

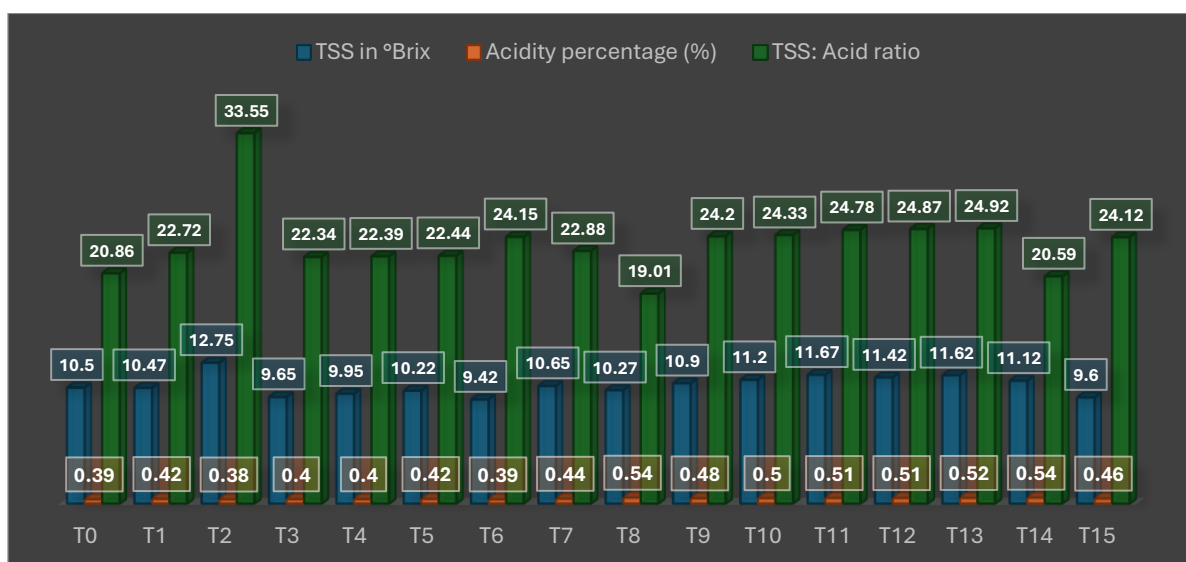


Fig. 1. TSS, Acidity and TSS: Acid ratio

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

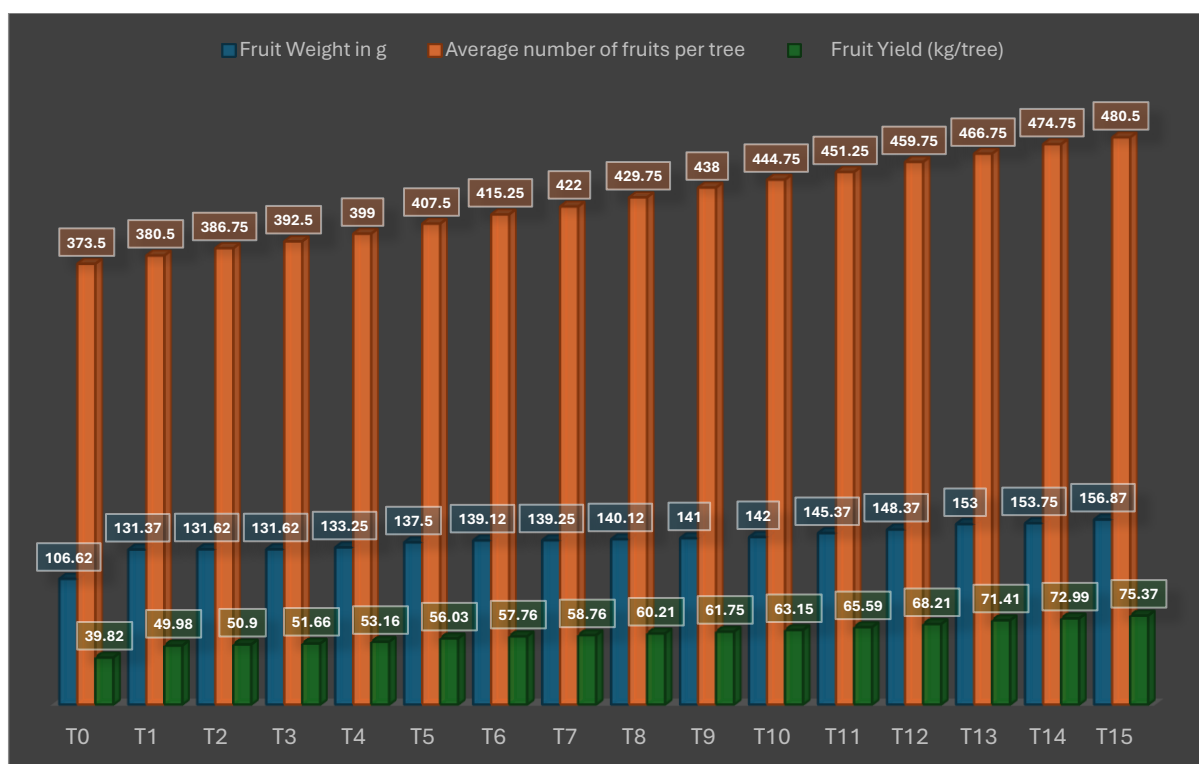


Fig. 2. Fruit weight, average number of fruits per tree, fruit Yield

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/cm ²)
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

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	0.46	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

Treatments	TSS in °Brix	Acidity percentage (%)	TSS: Acid ratio
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	0.54	24.12
C.D. at 5%	0.916	0.013	3.0533

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

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.

The foliar application of manganese sulfate (MnSO_4) and iron sulfate (FeSO_4) at varying concentrations significantly influenced the fruit quality, yield, and nutritional attributes of Daisy mandarin grown in loamy soil with a pH of 7.86 and 0.47% organic matter. This study highlights the critical role of micronutrients, particularly manganese (Mn) and iron (Fe), in enhancing citrus fruit quality and yield, addressing deficiencies prevalent in alkaline soils with low organic matter content. The results align with and expand upon prior research, demonstrating the synergistic effects of Mn and Fe in optimizing physiological and biochemical processes in citrus crops.

3.1 Fruit Quality Parameters

3.1.1 Juice content, vitamin C, and fruit firmness

The treatment T14 (0.3% MnSO_4 + 0.2% FeSO_4) significantly enhanced juice content, vitamin C levels, and fruit firmness, achieving results comparable to T15 (0.3% MnSO_4 + 0.3% FeSO_4). These improvements can be attributed to the role of Mn and Fe in enzymatic activities and metabolic pathways critical for fruit development. Manganese is a cofactor in enzymes such as superoxide dismutase, which mitigates oxidative stress, thereby preserving cell integrity and enhancing juice vesicle development (Liu et al., 2012). Iron, essential for chlorophyll synthesis and photosynthesis, likely contributed to improved carbohydrate allocation to fruits, supporting higher juice content and firmness. The synergistic effect of Mn and Fe in T14 and T15 likely optimized these processes, leading to superior fruit quality. In contrast, the control treatment (T0, water sprays) exhibited the lowest juice content, vitamin C, and firmness, underscoring the impact of Mn and Fe deficiencies in the loamy soil, as noted by Singh & Malhotra (2011).

3.1.2 Total soluble solids (TSS) and TSS: acid ratio

The highest total soluble solids (TSS) and TSS: acid ratio were recorded in T2 (0.2% MnSO_4), with a TSS: acid ratio of 33.55, indicating a pronounced sweetness due to elevated sugar accumulation and reduced acidity (0.38%). The low acidity in T2 reflects the typical inverse relationship between sugar content and acidity during fruit ripening, as sugars accumulate while organic acids are metabolized (Haque et al.,

2022). Conversely, T15 (0.3% MnSO_4 + 0.3% FeSO_4) recorded the lowest TSS, suggesting that excessive micronutrient concentrations may disrupt carbohydrate synthesis, possibly due to feedback inhibition of photosynthetic enzymes or nutrient imbalances. The lowest TSS: acid ratio (19.01) was observed in T8 (0.1% MnSO_4 + 0.2% FeSO_4), indicating a higher acid content (0.54%), which may appeal to consumers preferring a balanced flavor profile (Hussain et al., 2021).

3.1.3 Fruit weight, number, and yield

The treatment T15 (0.3% MnSO_4 + 0.3% FeSO_4) resulted in the highest fruit weight, number of fruits per plant, and yield per plant, corroborating the findings of (Haque et al., 2022). Higher Mn and Fe concentrations likely enhanced cell division and expansion during fruit development, as Mn supports auxin synthesis and Fe facilitates energy transfer in mitochondria. The increased fruit number and yield in T15 suggest improved reproductive growth and sink strength, driven by efficient nutrient assimilation. In contrast, the control treatment (T0) showed the lowest fruit weight, number, and yield, reflecting the limitations imposed by Mn and Fe deficiencies in the alkaline, low-organic-matter soil. These deficiencies likely impaired photosynthesis and nutrient transport, reducing fruit set and development.

3.1.4 Soil and micronutrient interactions

The loamy soil's high pH (7.86) and low organic matter (0.47%) likely reduced the bioavailability of Mn and Fe, as alkaline conditions promote the formation of insoluble complexes (Hussain et al., 2021). Foliar application bypassed soil limitations, delivering Mn and Fe directly to the plant, thereby enhancing nutrient uptake and utilization. The control treatment's poor performance across all parameters underscores the necessity of micronutrient supplementation in such soils. The synergistic effects of Mn and Fe in treatments like T14 and T15 highlight their complementary roles in photosynthesis, enzyme activation, and stress mitigation, which are critical for citrus growth and quality.

3.1.5 Comparison with previous studies

The results are consistent with prior studies that emphasize the importance of Mn and Fe in citrus production. Anitha et al. (2022) reported that Mn applications improve antioxidant enzyme activity,

enhancing fruit quality under stress conditions. However, the reduced TSS in T15 suggests a threshold beyond which excessive micronutrients may negatively affect carbohydrate metabolism, as supported by Dhaliwal *et al.* (2023). The superior yield in T15 corroborates Pawar *et al.* (2019), who demonstrated that combined Mn and Fe applications maximize fruit production.

4. IMPLICATIONS AND RECOMMENDATIONS

The findings suggest that foliar applications of 0.3% MnSO_4 + 0.2% FeSO_4 (T14) and 0.3% MnSO_4 + 0.3% FeSO_4 (T15) are highly effective for improving Daisy mandarin fruit quality and yield, particularly in alkaline, nutrient-deficient soils. For growers prioritizing sweetness and flavor, T2 (0.2% MnSO_4) is recommended due to its high TSS and TSS: acid ratio. However, excessive micronutrient applications, as seen in T15, should be approached cautiously to avoid impairing TSS accumulation. Future research should explore optimal Mn and Fe ratios across different citrus varieties and soil types, as well as the long-term effects of foliar applications on tree health and sustainability.

5. CONCLUSION

Foliar application of MnSO_4 and FeSO_4 significantly enhances Daisy mandarin fruit quality, yield, and nutritional attributes, with T14 and T15 emerging as the most effective treatments for juice content, vitamin C, firmness, and yield. The high TSS and TSS: acid ratio in T2 highlight its suitability for flavor-focused production. These results underscore the importance of tailored micronutrient applications to address soil deficiencies and optimize citrus production, providing valuable insights for growers in similar agroecological conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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