Influence of Kaolin, Calcium Oxide, and Boron Trioxide Sprays to Reduce Sunburn and Enhance Fruit Productivity and Quality in Murcott Mandarin

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Climate change has increasingly disrupted the growth and development of many fruit crops. Among the associated challenges, sunburn caused by excessive light and solar radiation is a major physiological disorder affecting citrus and other fruit species. This study evaluated the potential of kaolin (KL), calcium oxide (CaO), and boric acid (B_2O_3) to mitigate sunburn and improve fruit set, yield, and quality in Murcott mandarin. Foliar sprays were applied at concentrations of 2000, 3000, and 4000 ppm KL, either alone or in combination with CaO and B_2O_3 at 0 CaO + 0 B_2O_3, 500 ppm CaO + 50 ppm B_2O_3, and 1000 ppm CaO + 100 ppm B_2O_3. Applications were performed four times during each season (mid-March, early July, early August, and early September) in 2023 and 2024. The results demonstrated that foliar application of KL, CaO, and B_2O_3 significantly increased fruit set, yield, and both physical and chemical quality attributes by reducing sunburn incidence across both study seasons. The most effective treatments were 4000 ppm KL + 500 ppm CaO + 50 ppm B_2O_3 and 4000 ppm KL + 1000 ppm CaO + 100 ppm B_2O_3.

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INTRODUCTION

Fruit trees are highly vulnerable to environmental stresses, and the severity of these stresses has intensified in recent years due to climate change (Rachappanavar *et al*. 2022). Elevated temperatures impair photochemical activity and reduce light energy conversion efficiency, with excessive heat and radiation damaging the photosystems (Sun *et al*. 2018). Photosynthesis is particularly sensitive to high temperatures, leading to rapid declines under intense light conditions (Ahammed *et al*. 2018). During summer, when temperatures exceed 45 °C, sunburn damage can cause yield losses of up to 40% (Sarooghinia *et al*. 2020). The combined effects of strong solar radiation, high temperature, and low humidity trigger physiological disorders that markedly decrease fruit yield and quality (Kalcsits *et al*. 2017). Sunburn typically appears as peel discoloration and surface burns, progressing to large necrotic black patches on the fruit skin (Pareek *et al*. 2015).

Fertilizers and spraying of particle suspensions have emerged as promising strategies to enhance photosynthesis, improve leaf development, and promote overall plant vigor, while simultaneously reducing nutrient losses compared with conventional fertilizers. Their high efficiency not only improves yield and fruit quality but also minimizes negative environmental impacts such as soil pollution and nutrient leaching (Usman *et al*. 2020; Jakhar *et al*. 2022). Due to their small particle size and high absorption capacity, nanoparticles can improve nutrient delivery and uptake efficiency (Yadav *et al*. 2023).

Kaolin (KL) has been widely studied as a protective agent against abiotic stress. When applied as a foliar spray, KL forms a reflective barrier on leaves and fruits that lowers tissue temperature, mitigates solar radiation stress, reduces transpiration, and ultimately enhances fruit yield and quality (Glenn and Puterka 2010). KL reduces sunburn injury by reflecting ultraviolet and infrared radiation, without interfering with stomatal function or photosynthesis (Ergun 2012; Glenn 2012). In olive trees, KL application under water-limited conditions improved photosynthetic rates (Denaxa *et al*. 2012). Similarly, in mango, KL coatings alleviated high irradiance stress, decreased leaf temperature and vapor pressure deficit, and increased photosynthesis, gas exchange, fruit set, and total yield (Chamchaiyaporn *et al*. 2013). Other studies reported that KL improves plant growth, dry matter accumulation, and water use efficiency under stress, while reducing transpiration, tissue temperature, and leaf thickness (Segura-Monroy *et al*. 2015). As a natural clay mineral, KL acts as both a reflective agent and an antitranspirant, enhancing photosynthetic efficiency and stress tolerance (Ramírez-Godoy *et al*. 2018). It has been shown to reduce canopy temperature (Luciani *et al*. 2020), improve gas exchange under drought and salinity (Abdallah 2019), and alter biochemical traits such as soluble solids and anthocyanin levels in grapes (Cataldo *et al*. 2022; Brito *et al*. 2019).

Saure (2005) emphasized that calcium is crucial for membrane stability and cell integrity. It helps prevent chlorophyll degradation, improves trees' nutritional quality by increasing chlorophyll content, leaf area, and water uptake, and enhances fruit nutrient levels. This, in turn, boosts photosynthetic efficiency, positively impacting vegetative growth and yield. Calcium, which is commonly applied as $CaCl_2$ or $Ca(NO_3)_2$, plays essential roles in plant growth, development, and stress responses. It supports photosynthesis by activating key metabolic enzymes (Akhtar *et al*. 2010), regulates auxin function, and promotes cell division, elongation, and pollen tube growth (Fageria 2009). In grape, calcium contributes to flowering, fruit set, cluster weight, and cell expansion (Bonomelli and Ruiz 2010). Preharvest $CaCl_2$ sprays reduce postharvest decay and physiological disorders (Madani *et al*. 2014), while enhancing antioxidant levels and secondary metabolites (Ghesmati *et al*. 2017; Vighi *et al*. 2019). Calcium strengthens the cell wall through the formation of Ca-pectate complexes, improving fruit firmness and delaying ripening (Zhang *et al*. 2019; Jaime-Guerrero *et al*. 2024). In addition, calcium regulates ethylene production, respiration, chlorophyll development, and senescence (Mounika *et al*. 2021). Calcium has shown promise in improving fruit yield (Gao *et al*. 2019), enhancing stress tolerance under salinity and drought (Nasrallah *et al*. 2022), and improving storage and shelf life (Zhou *et al*. 2018; Huang *et al*. 2023).

Boron (B) is another essential nutrient that plays critical roles in photosynthesis, stomatal conductance, carbohydrate metabolism, and reproductive development. Adequate boron supply improves photosynthetic efficiency, pollen germination, tube elongation, flowering, and fruit set (Sotiropoulos *et al*. 2002; Marschner 2012). Boron oxide (B_2O_3) is recognized as an essential factor in regulating the translocation of sugars and carbohydrates within plant systems. In olive (*Olea europaea* L.), boron deficiency markedly diminishes pollen viability, fruit set, and the normal differentiation of reproductive organs. Furthermore, insufficient boron availability compromises the mechanical stability of the leaf cuticle, frequently resulting in epidermal fissuring. Such structural impairments adversely affect stomatal functionality, thereby reducing their efficiency in the foliar uptake of nutrient solutions (Khayyat *et al*. 2007). Boron deficiency reduces cell division and photosynthetic activity, while affecting structural integrity of cell walls by limiting Ca–pectin binding (Ardic *et al*. 2009; Gupta and Solanki 2013). In various fruit crops, borax application improves fruit set, sugar transport, the metabolism of carbohydrates, nucleic acids, indole acetic acid, and phenols, seed development, and overall productivity (Xu *et al*. 2015; Mohammed *et al*. 2018; Shireen *et al*. 2018; Bons and Sharma 2023). It also enhances vitamin C and soluble protein content, maintains cell membrane integrity, and increases metabolic activity (Milagres *et al*. 2019; Xu *et al*. 2021; Li *et al*. 2023).

Given the importance of these nutrients, the present study was conducted to evaluate whether foliar application of kaolin, calcium, and boron compounds could mitigate sunburn damage in Murcott mandarin while improving fruit yield and quality.

Materials and Methods

Experimental site and applied treatments

The experiment was conducted during the 2023 and 2024 seasons on eight-year-old Murcott mandarin (*Citrus reticulata*) trees grafted onto *Citrus volkameriana* rootstock, spaced 4 × 5 m apart. The orchard was located in El-Nubaria, Beheira Governorate, Egypt, with trees grown in sandy soil under drip irrigation. Soil characteristics are presented in Table 1.

Sixty uniform trees were selected and subjected to the same cultural practices throughout both seasons. Treatments consisted of foliar sprays of kaolin (KL: 2, 3, or 4 g/L), calcium oxide (CaO: 0, 0.5, or 1 g/L), and boric acid (B_2O_3: 0, 50, or 100 mg/L), as well as an untreated control (Table 2). Sprays were applied four times each season: mid-March, early July, early August, and early September. Treatments were arranged in a randomized complete block design (RCBD) with five replicates (one tree per replicate), giving a total of 60 trees. Spray solution volume was 20 L per tree, prepared with tap water.

Fruit Set %, fruit drop %, and fruit number

At full bloom in April, the total number of flowers was recorded, and fruit set (%) was calculated (Eq. 1).

$$\text{Fruit set \%} = \frac{No.of\ set\ fruits}{No.of\ flowers} \times 100 \tag{1}$$

The fruit drop percentage was calculated by Eq. 2.

$$\text{Fruit drop \%} = \frac{No.of\ fruitlets\ at\ initial\ set - No.of\ harvested\ fruits}{No.of\ fruitlets\ at\ initial\ set} \times 100 \tag{2}$$

Fruit Yield (ton/ha)

Fruit yield (t/ha) was calculated by multiplying the average fruit weight per tree by the number of trees per hectare.

Table 1. Soil Analysis

Sand			90.8%
Silt			6.55%
Clay			2.65%
Textural class			Sandy
Organic matter			0.275%
pH			8.26
$CaCO_3$			4.8%
EC (dS/m)			1.2
Soluble anions meq/L)		HCO_3^-	3.12
		CL^-	4.57
		SO_4^{--}	4.91
Soluble cations (meq/L)		Ca^{++}	2.22
		Mg^{++}	1.5
		Na^+	3.66
		K^+	4.42
Available nutrients (mg/kg)	Macronutrients	N	117.5
		P	15.2
		K	297.5
	Micronutrients	Fe	1.9
		Zn	0.38
		Mn	1.85

Table 2. Weather Data during the Experimental Seasons of 2023 and 2024

Year	2023	2024	2023	2024	2023	2024	2023	2024
Months	Minimum Temperature (°C)		Maximum Temperature (°C)		Average Relative Humidity (%)		Total Precipitation (mm)	
January	11.89	12.20	20.35	19.84	72.73	66.88	31.70	28.20
February	10.61	11.50	18.87	20.30	68.77	71.17	48.70	13.90
March	12.75	12.55	23.43	23.27	63.57	64.55	19.00	8.90
April	14.39	15.70	26.33	28.03	59.06	63.53	16.00	2.80
May	17.36	18.07	29.53	29.92	59.56	55.40	0.40	0.00
June	20.98	22.39	32.63	35.66	60.92	58.55	2.40	0.30
July	23.70	24.64	35.93	35.61	61.01	60.53	0.00	0.00
August	24.36	24.73	35.00	35.54	60.61	59.61	0.00	0.00
September	24.05	23.87	34.80	33.45	60.11	60.04	0.60	0.00
October	21.30	20.47	30.15	29.77	65.05	62.07	4.30	0.00
November	18.05	17.01	26.89	24.72	63.62	65.22	5.00	6.80

Table 3. Applied Treatments

T1	0 KL + 0 CaO + 0 B_2O_3
T2	0 KL + 500 ppm CaO + 50 ppm B_2O_3
T3	2000 ppm KL + 0 CaO + 0 B_2O_3
T4	0 KL + 1000 ppm CaO + 100 ppm B_2O_3
T5	3000 ppm KL + 0 CaO + 0 B_2O_3
T6	2000 ppm KL + 500 ppm CaO + 50 ppm B_2O_3
T7	4000 ppm KL + 0 CaO + 0 B_2O_3
T8	2000 ppm KL + 1000 ppm CaO + 100 ppm B_2O_3
T9	3000 ppm KL + 500 ppm CaO+ 50 ppm B_2O_3
T10	3000 ppm KL + 1000 ppm CaO + 100 ppm B_2O_3
T11	4000 ppm KL + 500 ppm CaO + 50 ppm B_2O_3
T12	4000 ppm KL + 1000 ppm CaO + 100 ppm B_2O_3

Physical fruit quality

Fruit length and diameter (cm) were measured using a digital Vernier caliper. Average fruit weight was recorded from 10 representative fruits. Fruit volume (cm^3) was determined by water displacement in a 1000 mL graduated cylinder. Firmness (kg/cm^2) was measured with a Magness–Taylor pressure tester. Sunburn incidence (%) was determined using Eq. 3:

$$\text{Fruit sun scalds \%} = \frac{\text{Number of sun scald fruits}}{total\ number\ of\ fruits} \times 100 \quad (3)$$

Chemical fruit quality

Total soluble solids (TSS %) in the juice of fruits were measured by using a hand refractometer (ATAGO, Tokyo, Japan). Total acidity (%) was determined as citric acid/100 milliliters of fruit juice (AOAC 2005). The phenol-sulfuric acid method was used to estimate the total sugars by using 1.0 mL of sample treated with 1.0 mL of 5% phenol and 5.0 mL of concentrated H_2SO_4 and measured at 485 nm. Reduced sugars were estimated by using the 3,5-dinitro salicylic acid (DNS) method by using 2.0 mL of the sample and 1.5 mL of DNS at 80 °C for 10 min and measuring at 510 nm (Lam *et al.* 2021). The content of ascorbic acid was determined by titration using 2, 6-dichloro phenol indophenol (Nielsen 2017). Fruit carotene content was measured using the method of (Aquino *et al.* 2018) at a wavelength of 440 nm.

Nutritional Status

After harvesting the fruits in the 2023 and 2024 seasons, 40 leaves from the middle part of the shoots were collected from each tree (Arrobas *et al.* 2018). After washing the leaves very well with tap water, they were washed again with distilled water, dried at 70 °C until constant weight, and ground and digested using H_2SO_4 and H_2O_2 until the solution became clear.

The nitrogen content was determined using the micro Kjeldahl method (Wang *et al.* 2016). The phosphorus content was measured using the Vanadomolybdo method (Wieczorek *et al.* 2022). Potassium content was determined using a flame photometer (Asch *et al.* 2022). Atomic absorption spectrophotometry was used to measure the content of Ca, and B.

Statistical Analysis

Data were analyzed by one-way analysis of variance (ANOVA) using CoHort Software 6.311 (Pacific Grove, CA, USA). Treatment means were compared using the least significant difference (LSD) test at the 0.05 probability level (Snedecor and Cochran 2021).

RESULTS

Fruit set percentage, fruit weight, fruit number, and overall yield were significantly improved by foliar spraying of KL in combination with calcium and boron compared with the control (Table 4; Fig. 1). The greatest increases were observed with treatment T12, followed by T11, T10, and T9, which all showed significant improvements over untreated trees in both seasons.

Table 4. Effect of the Foliar Spraying of Kaolin, CaO, and B_2O_3 on the Fruit Set %, Fruit Weight, and Number in Murcott Mandarin during 2023 and 2024

Treatments	Fruit Set (%)		Fruit Weight (g)		Fruit Number	
	2023	2024	2023	2024	2023	2024
T1	3.75f	4.38e	173.25g	174.88h	302.67f	305.33e
T2	3.9f	4.56e	174.06g	176.68gh	311.67e	311.33d
T3	4.19e	4.81d	175.04g	176.60gh	312.67e	318.67c
T4	4.29de	4.90cd	179.67f	178.76g	316.33de	321.67c
T5	4.32de	4.89cd	182.82e	182.16f	319.33cd	327.00b
T6	4.36cde	4.88cd	183.54de	184.71ef	324.00bc	327.00b
T7	4.39cde	4.89cd	184.96d	186.19de	324.67bc	329.00ab
T8	4.49bcd	5.03c	186.93c	188.54cd	326.33ab	329.33ab
T9	4.57bc	5.08bc	187.43c	190.85bc	328.67ab	329.33ab
T10	4.59bc	5.27ab	187.36c	190.53bc	329.67ab	332.33a
T11	4.66b	5.31a	191.67b	192.62b	329.67ab	331.67ab
T12	5.11a	5.39a	198.20a	198.66a	331.00a	333.00a
$LSD_{0.05}$	0.21	0.20	1.79	2.85	5.23	4.67

Note: No significant differences between the treatments that have the same letters in each column. The explanation for the treatments is demonstrated in Table 2.

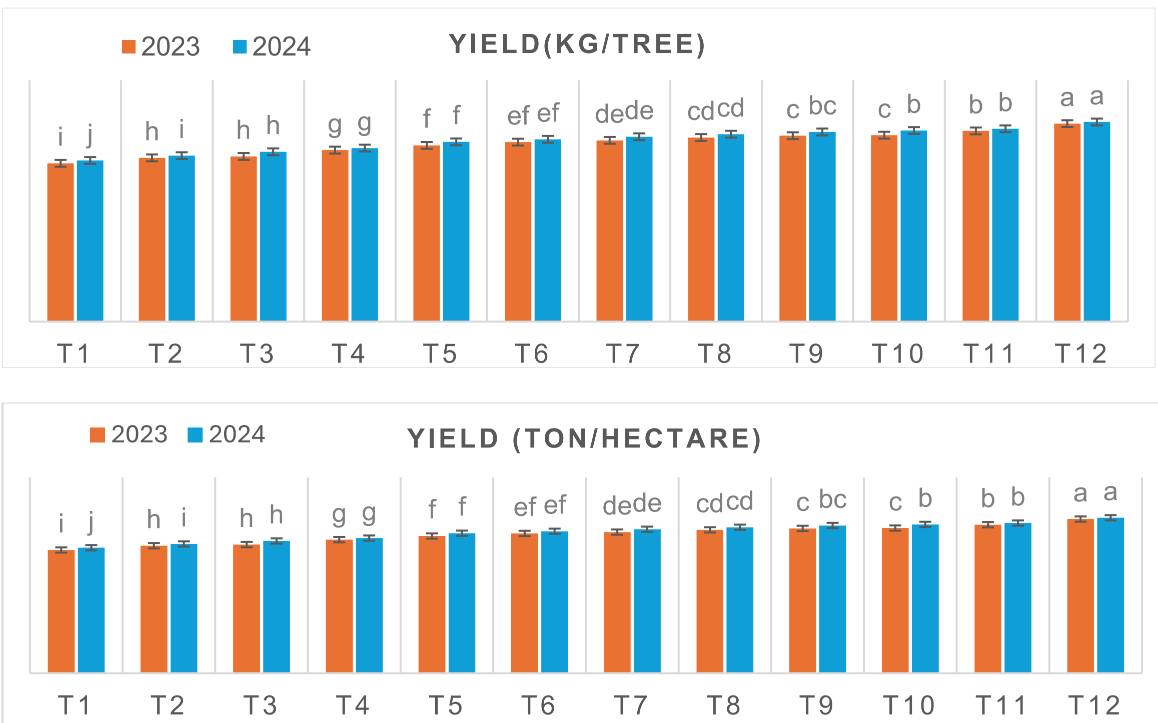

Fig. 1. The effect of the foliar spraying of KL, CaO, and B_2O_3 on the fruit yields in kg per tree and in ton per hectare in Murcott mandarin during 2023 and 2024 seasons

Fruit volume, length, and diameter were also significantly enhanced by KL + CaO + B_2O_3 applications (Table 5). Among the treatments, T12 produced the highest values, while T11 and T10 also markedly improved these parameters relative to the control.

Table 5. Effect of the Foliar Spraying of Kaolin, CaO, and B_2O_3 on the Fruit Volume, Length, and Diameter in Murcott Mandarin during 2023 and 2024

Treatments	Fruit Volume (cm^3)		Fruit Length (cm)		Fruit Diameter (cm)	
	2023	2024	2023	2024	2023	2024
T1	180.58g	182.11h	5.31e	5.26 e	6.15e	6.18f
T2	181.39g	183.78gh	5.38de	5.34de	6.17de	6.20ef
T3	182.37g	184.00gh	5.42de	5.36cde	6.18de	6.20ef
T4	187.34f	186.23g	5.45de	5.41cde	6.20cde	6.20ef
T5	189.82e	189.36f	5.47de	5.47cd	6.23cd	6.23def
T6	190.54de	192.18ef	5.54cd	5.49cd	6.24c	6.24de
T7	192.62cd	193.62de	5.67bc	5.52bcd	6.29b	6.26cd
T8	193.60c	196.01cd	5.67bc	5.56bc	6.31b	6.26cd
T9	194.43c	198.15bc	5.75b	5.69b	6.31b	6.32bc
T10	194.36c	200.06b	5.79ab	5.93a	6.31b	6.34b
T11	198.67b	197.93bc	5.84ab	5.95a	6.35b	6.34b
T12	205.53a	205.96a	5.93a	5.98a	6.42a	6.41a
$LSD_{0.05}$	2.21	2.82	0.16	0.18	0.05	0.06

Note: No significant differences between the treatments that have the same letters in each column

Fruit juice percentage and firmness increased significantly in trees treated with KL + CaO + B_2O_3 (Table 6). Treatment T12 achieved the greatest improvement, whereas T11, T10, and T9 also produced positive effects compared with untreated trees in both seasons. In contrast, sunburn incidence was markedly reduced by T12, T11, and T10, with moderate reductions observed in T9 and T8 compared to the control.

Table 6. Effect of the Foliar Spraying of Kaolin, CaO, and B_2O_3 on Sunburn and Fruit Juice Percentages, and Fruit Firmness in Murcott Mandarin during 2023 and 2024

Treatments	Sunburn (%)		Juice (%)		Fruit Firmness (kg/cm^2)	
	2023	2024	2023	2024	2023	2024
T1	13.90a	13.50a	48.10f	50.10g	2.20c	2.23c
T2	13.00b	12.60b	49.49ef	51.60fg	2.23bc	2.23c
T3	12.50bc	12.00bc	49.87ef	51.62fg	2.24bc	2.24c
T4	12.00cd	11.79c	51.13de	52.87ef	2.23 bc	2.26c
T5	11.80cd	11.43cd	51.53de	53.00ef	2.26b	2.26c
T6	11.74d	10.79de	51.67de	53.67def	2.26b	2.27c
T7	10.47e	10.30e	52.37cd	54.33de	2.26b	2.27c
T8	10.29ef	9.53f	52.43cd	55.27de	2.26b	2.28c
T9	10.26ef	9.30f	54.33c	56.20cd	2.27b	2.33b
T10	9.67f	8.43g	54.43c	58.33c	2.34a	2.36b
T11	8.90g	8.30g	56.80b	62.33b	2.35a	2.37b
T12	8.25g	7.83g	61.91a	65.00a	2.38a	2.45a
$LSD_{0.05}$	0.67	0.75	2.17	2.43	0.04	0.05

Note: No significant differences between the treatments that have the same letters in each column

Chemical fruit quality also responded positively to kaolin + CaO + B_2O_3. Total soluble solids (TSS), vitamin C, and carotene content were significantly increased, with T12 again being the most effective treatment (Table 7). T11, T10, T9, and T8 also showed substantial improvements compared with untreated trees. At the same time, fruit acidity was significantly reduced by all treatments, with T12 producing the greatest reduction across both seasons.

Table 7. Effect of the Foliar Spraying of Kaolin, CaO, and B_2O_3 on Fruit Total Soluble Solids, and Acidity Percentages, Vitamin C, and Carotene in Murcott Mandarin during 2023 and 2024

Treatment	TSS (%)		Acidity (%)		VC (mg/100 mL Juice)		Carotene (mg/100g)	
	2023	2024	2023	2024	2023	2024	2023	2024
T1	8.69h	9.38f	1.35a	1.23a	29.93e	30.47h	2.78e	2.81f
T2	9.00gh	9.43f	1.24b	1.23a	30.68de	31.43gh	2.90de	3.07e
T3	9.24fg	9.93e	1.167c	1.20ab	31.13cde	32.22fg	2.95d	3.17e
T4	9.39efg	10.21de	1.137cd	1.157b	32.19cd	32.05fg	3.02cd	3.14de
T5	9.52ef	10.49d	1.12cd	1.10c	31.32cde	33.14ef	3.02cd	3.26cd
T6	9.88de	11.11c	1.10de	1.08cd	32.21cd	34.33de	3.14bc	3.28bc
T7	10.19cd	11.18c	1.10de	1.06cd	32.18cd	34.60cd	3.15bc	3.40ab
T8	10.23bcd	11.29c	1.09de	1.08cd	32.91bc	35.82bc	3.17b	3.42a
T9	10.37bcd	11.52bc	1.05e	1.07 cd	32.17cd	36.53b	3.19ab	3.43a
T10	10.53bc	11.83b	0.98f	1.04de	34.46ab	36.63b	3.23ab	3.41a
T11	10.73b	11.94b	0.91g	1.00e	35.02a	36.87b	3.28ab	3.46a
T12	11.45a	12.40a	0.88g	0.86f	36.16a	38.30a	3.32a	3.48a
$LSD_{0.05}$	0.46	0.46	0.05	0.04	1.67	1.22	0.13	0.12

Note: No significant differences between the treatments that have the same letters in each column

Sugar fractions were strongly affected by the treatments (Table 8). T12 and T11 significantly increased total sugars, reducing sugars, and non-reducing sugars, while T10, T9, T8, and T7 also enhanced sugar content relative to the control.

Leaf mineral composition was similarly improved (Table 9). Foliar sprays of KL + calcium + boron significantly increased leaf concentrations of N, P, K, Ca, and B compared with untreated trees. T12 consistently produced the highest nutrient contents, followed by T11, T10, T9, and T8.

Table 8. Effect of the Foliar Spraying of Kaolin, CaO, and B_2O_3 on Fruit Content from the Total, Reduced, and Non-reduced Sugars in Murcott Mandarin during 2023 and 2024

Treatments	Total Sugars (%)		Reduced Sugars (%)		Non-reduced Sugars (%)	
	2023	2024	2023	2024	2023	2024
T1	5.47e	6.13d	3.05d	3.55f	2.42de	2.58d
T2	5.47e	6.28d	3.10d	3.58f	2.37e	2.70 bcd
T3	5.48e	6.33d	3.15d	3.77de	2.33e	2.57d
T4	5.57de	6.43d	3.12d	3.70ef	2.453de	2.73bcd
T5	5.80c	6.45d	3.25d	3.77de	2.55d	2.68cd
T6	5.75cd	6.55d	3.20d	3.88cde	2.54d	2.68cd
T7	6.28b	7.03c	3.55bc	3.88cde	2.73c	3.15a
T8	6.36b	7.05c	3.57bc	3.93cd	2.79c	3.11ab
T9	6.47b	7.11bc	3.53bc	4.04bc	2.94b	3.07abc
T10	6.48b	7.47ab	3.50c	4.05bc	2.98b	3.43a
T11	6.87a	7.58a	3.73ab	4.17b	3.14a	3.41a
T12	6.93a	7.66a	3.81a	4.51a	3.12a	3.15a
$LSD_{0.05}$	0.21	0.4	0.19	0.17	0.12	0.38

Note: No significant differences between the treatments that have the same letters in each column

Table 9. Effect of the Foliar Spraying of Kaolin, CaO, and B_2O_3 on Leaf Content from Nitrogen, Phosphorous, Potassium, Calcium, and Boron in Murcott Mandarin during 2023 and 2024

Treatments	N%		P%		K%		Ca%		B (ppm)	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
T1	1.62f	1.76g	0.52f	0.52g	1.43e	1.48g	1.37g	1.35h	43.33g	43.00g
T2	1.62f	1.78g	0.53f	0.53g	1.43e	1.50fg	1.37g	1.37gh	45.00fg	44.67g
T3	1.64f	1.80fg	0.52f	0.57f	1.45e	1.50fg	1.41fg	1.38gh	45.67fg	45.67fg
T4	1.70e	1.83ef	0.53f	0.58ef	1.45e	1.53f	1.40fg	1.43fg	46.33efg	46.33fg
T5	1.73d	1.83ef	0.54f	0.60e	1.46e	1.58e	1.44ef	1.45ef	47.33ef	45.67fg
T6	1.74d	1.84ef	0.54f	0.63d	1.52d	1.66d	1.45def	1.50de	49.33de	48.33ef
T7	1.82c	1.86de	0.58e	0.63d	1.52d	1.68d	1.43f	1.54cd	51.67cd	51.33de
T8	1.83c	1.90cd	0.59de	0.64d	1.60c	1.74c	1.48de	1.52d	54.67c	54.33d
T9	1.84c	1.94bc	0.62cd	0.65d	1.61c	1.83b	1.49cd	1.59c	60.33b	60.00bc
T10	1.88b	1.99b	0.64bc	0.68c	1.68b	1.84b	1.53c	1.66b	59.33b	58.33c
T11	1.93a	2.04a	0.66b	0.72b	1.72a	1.87a	1.59b	1.67b	62.00ab	62.00b
T12	1.93a	2.06a	0.70a	0.76a	1.73a	1.90a	1.65a	1.73a	65.00a	66.00a
$LSD_{0.05}$	0.03	0.04	0.03	0.02	0.03	0.04	0.04	0.06	3.27	3.10

Note: No significant differences between the treatments that have the same letters in each column

DISCUSSION

In this study, foliar application of kaolin (KL), calcium oxide (CaO), and boron trioxide (B_2O_3) significantly reduced fruit sunburn, enhanced fruit set, and improved both yield and fruit quality of Murcott mandarin trees. The combined treatment (T12) was consistently superior across both seasons, indicating a strong synergistic effect of these elements on productivity and fruit quality traits.

The positive effects of KL observed here agree with previous findings that KL enhances crop performance under heat stress. KL forms a reflective particle film that lowers fruit and leaf surface temperature, mitigates water loss, and optimizes physiological processes such as stomatal conductance and photosynthesis (Glenn and Puterka 2010; Dinis *et al*. 2018; Brillante *et al*. 2016). Studies on pear, olive, grapevine, and citrus similarly reported that KL sprays reduce sunburn, improve fruit set, and enhance both physical and biochemical quality traits (Colavita *et al*. 2011; Brito *et al*. 2018; Gullo *et al*. 2020; Terán *et al*. 2024). These benefits stem not only from reduced heat load but also from improved water use efficiency and the stimulation of primary and secondary metabolism, which contribute to higher fruit size, juice content, vitamin C, carotene, and sugar levels. Applying KL particle film promotes both primary and secondary metabolic processes in grapevines, thereby enhancing berry quality. In addition, it has been employed as a short-term strategy for mitigating climate change, as its reflective properties toward ultraviolet and infrared radiation help decrease leaf temperature and improve photosynthetic performance by alleviating photoinhibition (Conde *et al*. 2018). KL helps reduce water loss from transpiration and maintains a relatively open rate of stomata, thereby ameliorating the plant water content (Brito *et al*. 2019). KL can lower leaf temperature by up to 6.7 °C, promoting stomatal opening, which in turn boosts photosynthesis and improves plant tolerance to intense light and heat (de Abreu *et al*. 2022). Applying KL at concentrations of 2%, 4%, and 6% significantly improved fruit set percentage, yield, fruit weight, and firmness, while simultaneously reducing sunburn incidence in pomegranate (Al-Saif *et al*. 2022). Foliar KL application provides key nutrients and improves soil moisture retention, while its reflective properties lower leaf temperature and reduce water loss, collectively supporting cell division, elongation, and overall growth (Vani *et al*. 2023). KL alleviates environmental stress by minimizing leaf damage and abscission, protecting carotenoids, elevating proline, chlorophyll, and gas exchange, and regulating key hormones like abscisic acid, salicylic acid, indole-3-acetic acid, and jasmonic acid to strengthen stress tolerance (Terán *et al*. 2024). KL sprays at 3 and 6 % on apple improved tree crown and volume, increased fruit weight, fruit length, firmness, and fruit soluble solids (Faghih *et al*. 2021), enhanced leaf area, chlorophyll, photosynthesis, gas exchange, internal CO_2, water-use efficiency, potassium status, and kernel yield/quality, while reducing leaf temperature, fruit drop, sunburn, and cracking in Persian walnut (Gharaghani *et al*. 2018). Spraying KL at 3 and 6 % on 'Tardy Nonpareil' Almond trees improved shoot growth, prevented premature leaf abscission, water use efficiency and tree yield, reduced leaf temperature by up to 3.25 °C, and it increased the photosynthesis rate and stomata conductance, tree yield, and nut attributes, under water deficit (Gharaghani *et al*. 2023).

Calcium oxide application also was found to play a role in enhancing fruit quality in this study. As background, it is known that each type of calcium salt produces a different pH in distilled water, influencing its solubility. Calcium citrate has a higher solubility than calcium carbonate in water, the difference is minimal at pH 7.5. The partial pressure of

CO_2 reduced the solubility of calcium carbonate at pH 7.5. Soluble calcium calculations aligned with in-vivo data on absorbed calcium. The data highlight the influence of pH and CO_2 on the solubility of calcium salts in the presence of bicarbonate secretions in the intestine (Goss *et al*. 2007). Marschner (2012) noted that calcium plays a key role in binding proteins and polysaccharides in the cell wall, enhancing flowering, fruit maturation, and the transport of carbohydrates from leaves to fruits.

Calcium oxide spray enhances cell wall permeability, improving water and nutrient transport from leaves to fruits, which boosts fruit growth, maintains moisture balance between the peel and internal tissues, and preserves cell wall elasticity (Korkmaz and Askın 2015). Foliar $CaCl_2$ applications have been shown to improve fruit firmness, size, and storability by strengthening cell walls, maintaining water balance, and delaying senescence (Michailidis *et al*. 2020). The present results align with reports from pomegranate, apple, and kiwifruit where Ca sprays improved yield, fruit weight, soluble solids, and vitamin C while reducing acidity and sunburn (Ramírez-Godoy *et al*. 2018; Denaxa *et al*. 2023; Fahmy *et al*. 2023). The improvements in firmness and reduced sunburn incidence observed in the present study further support Ca's protective role under environmental stress. $CaCl_2$ application in fruits helps maintain firmness and cell turgor, while preventing physiological disorders (Jain *et al*. 2019). The spraying of 100 and 200 $CaCO_3$ notably increased the stem thickness and plant height, which are essential for supporting the overall structure and stability of the plant, and this improvement can be attributed to Ca's crucial role in maintaining cell wall integrity and promoting cell division and elongation (Nangare *et al.* 2020; Mogazy *et al.* 2022). Applying $CaCl_2$ at 1.5 and 2.0% on apple significantly improved fruit physical attributes such as fruit firmness, fruit diameter, length, weight, and size, fruit content from anthocyanin, phenols, TSS, acidity, starch content, and fiber content (Ranjbar *et al.* 2020). Spraying pomegranate trees cv. Wonderful with $CaCl_2$ at 2 and 3 % noticeably improved the fruit weight, number and fruit yield, fruit dimensions, as well as fruit content from soluble solids, and vitamin C, while it significantly reduced the fruit acidity, fruit drop percentages and fruit sunburn percentages (Fahmy *et al*. 2023). Calcium oxide (CaO), commonly called quicklime, is a white to grayish solid obtained by heating calcium carbonate to release carbon dioxide. At room temperature, it readily reabsorbs carbon dioxide from the air and reacts vigorously with water to form calcium hydroxide, $Ca(OH)_2$, releasing heat in the process—hence the term "quick," or living, lime. This exothermic reaction has been used in portable heat sources. One of the oldest manufactured chemical products, quicklime is widely applied in construction, industrial neutralization processes, and occasionally as fertilizer, though calcium carbonate is generally preferred for agriculture. When water acts on CaO, it produces calcium hydroxide, also known as slaked lime. Only a small amount dissolves to yield limewater, while the remainder forms a suspension called milk of lime. Calcium hydroxide serves as an industrial alkali and a key ingredient in mortars, plasters, and cement. It also plays roles in the kraft paper process and in sewage treatment as a flocculant (Hanusa 2025).

Boron supplementation also contributed significantly to fruit set, retention, and overall productivity. Boron is essential for pollen germination, tube growth, sugar transport, and cell wall integrity, flower fertilization and ultimately improving the productivity (Davis *et al*. 2003; Bybordi and Malakouti 2006; Lewis 2019). Deficiency often results in flower drop, reduced fertilization, and lower leaf growth, root elongation, and yields (Han *et al*. 2008; Wang *et al*. 2015). The present findings agree with earlier reports by Ali *et al.* (2017), they noted that the external spraying of B_2O_3 at 0.2 and 0.3% improved the fruit set %, retained fruit number, fruit weight, pulp %, fruit productivity, fruit dimensions, and fruit content of chlorophyll, carotene, and vitamin C in mango and lowered the fruit drop percentage. Boron also has a vital role in cell structure and cell wall integrity (Lewis 2019) and in maintaining plasma membrane functions (Brown *et al*. 2002). The reduction in fruit drop from borax spraying may also be attributed to B's indirect role in auxin synthesis, which delays the formation of the abscission layer during the early stages of fruit development, ultimately increasing the percentage of fruit retention (Gupta *et al*. 2022). Mosa *et al*. (2015) noted that the spraying of apple with B_2O_3 at 0.2% markedly improved the shoot diameter, shoot length and leaf area, fruit set %, productivity, while it minimised the fruit acidity and fruit drop percentages. Spraying mandarin trees with borax at 0.04% boron remarkably improved the total flower and fruit set percentage and significantly reduced the flower and fruit drop percentages as compared to untreated trees (Ruchal *et al.* 2020). Sajid *et al*. (2024) reported that spraying B_2O_3 at 1% on three sweet cherry cultivars increased leaf area, fruit diameter, pulp %, total soluble solids, total sugars, fruit number, yield in kg, fruit set %, while it reduced the percentages of fruit drop and fruit acidity compared to untreated trees. Taken together, the combined application of KL, CaO, and B_2O_3 compounds improved both physiological efficiency and fruit quality traits in Murcott mandarin. KL primarily reduced heat and water stress, CaO enhanced cell wall strength and nutrient transport, and B_2O_3 optimized reproductive success and carbohydrate allocation. The synergistic effects of these treatments translated into higher fruit number, size, firmness, juice content, vitamin C, carotene, sugars, and leaf mineral concentrations.

These findings highlight the potential of integrated foliar sprays as an eco-friendly strategy to enhance citrus productivity and mitigate the negative impacts of abiotic stress. Further work should investigate the economic feasibility of large-scale adoption and the long-term effects of repeated applications on soil-plant interactions.

CONCLUSIONS

1. Foliar application of kaolin (KL) together with calcium oxide (CaO) and boron trioxide (B_2O_3) effectively mitigated the adverse effects of high temperature and solar radiation, reducing fruit sunburn and thereby increasing the proportion of marketable Murcott mandarin fruits.
2. The combined application of KL, CaO, and B_2O_3 compounds improved photosynthesis, fruit set, yield, and overall fruit quality.
3. The treatment with 4000 ppm KL + 1000 ppm CaO + 100 ppm B_2O_3 consistently produced the best results across all measured traits.

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Data Availability Statement

All the required data are included in the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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