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Effect of Foliar Spraying with Calcium and Boron on the Qualitative Characteristics of Local Orange (Citrus sinensis L.) Fruits

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I. Summary

A field experiment was conducted during the 2025 season in a local citrus orchard in the Salman Pak area / Al-Mada'in District / Baghdad Governorate / Iraq, on 15-year-old local orange trees (Citrus sinensis L.). The study aimed to investigate the effect of foliar spraying with calcium (Ca) and boron (B) on fruit quality traits. The experiment was designed according to a Randomized Complete Block Design (RCBD) as a factorial experiment with two factors: calcium at three levels (0, 100, 200 mg L^{-1}) and boron at three levels (0, 30, 60 mg L^{-1}), with three replications per treatment and two trees per experimental unit. Statistical analysis (ANOVA) was performed using Genstat 12th edition, and results were compared using the Least Significant Difference (LSD) test at a probability level of 0.05. The results showed highly significant differences for both calcium and boron factors and their interaction in all studied quality traits. The interaction $Ca_2 \times B_2$ (200 mg Ca L^{-1} + 60 mg B L^{-1}) recorded the highest value of total soluble solids (TSS) at 12.40%, compared to 9.80% in the control treatment, an increase of 26.5%. This interaction also recorded the highest percentage of total sugars at 7.10% compared to 5.20% in the control. Conversely, the $Ca_2 \times B_2$ interaction recorded the lowest percentage of total acidity (TA) at 0.65% compared to 0.98% in the control, leading to a rise in the TSS/TA maturity index to 19.08 compared to 10.00 in the control, an increase exceeding 90%. Vitamin C showed a marked increase, reaching 58.90 mg 100 mL^{-1} under the $Ca_2 \times B_2$ interaction compared to 42.50 in the control. Juice percentage increased from 38.50% to 49.10%, and fruit weight increased from 148.5 g to 202.6 g, while fruit volume increased from 185.0 cm^3 to 256.0 cm^3. These results confirm a clear synergistic effect between calcium and boron that surpasses the effect of each individually in improving the quality of local orange fruits. These findings contribute to the development of practical recommendations for foliar nutrition aimed at enhancing production quality and improving market value.

Keywords : *Orange, Calcium, Boron, Foliar nutrition, Leaf area, Chlorophyll, Vegetative growth*

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II. Introduction

Orange (Citrus sinensis L.) is one of the most important tropical and subtropical fruit crops in the world, representing about 40% of global citrus production, which is estimated at over 140 million tons annually. In Iraq, orange trees constitute an important economic pillar in the horticulture sector, with national production reaching 157,690 tons in the 2021 season, a 10.5% increase from the previous year (1). Orange orchards are concentrated in the governorates of Baghdad, Diyala, Wasit, and Salah al-Din, where the local cultivar is widely grown due to its tolerance of local environmental conditions and its suitability for Iraqi consumer tastes. The quality traits of orange fruits—such as the percentage of total soluble solids (TSS), total sugars, vitamin C, the TSS/TA maturity index, juice percentage, fruit weight, and fruit volume—are among the most prominent factors determining the marketability and nutritional value of oranges. Fruits rich in vitamins, carbohydrates, and minerals confer high health value, making them more acceptable to consumers and more successful in local and export markets (2).

1.1 Research Problem

Despite the notable expansion in local orange cultivation in Iraq, this agriculture faces several fundamental challenges that reduce production quality and market value:

First: Many Iraqi orange orchards suffer from a deficiency in micronutrients, particularly calcium and boron, due to the high pH of the dominant calcareous soils (pH 7.5–8.5), which restricts the solubility and root uptake of these elements. Calcium deficiency leads to weak fruit cell walls, rind cracking, early fruit drop, and reduced shelf life (3), while boron deficiency leads to disruption of carbohydrate metabolism, reduced sugar and vitamin C percentages, poor fruit set, and deformity (4).

Second: The near-total reliance on conventional soil fertilization, which is often wasteful and has low use efficiency, whereas recent studies have proven that foliar nutrition provides a rapid and direct response in plants, bypassing soil constraints and restoring elemental balance during critical stages of fruit development.

Third: The absence of clear, evidence-based fertilization recommendations derived from local experimental results concerning the concentrations of calcium and boron in foliar sprays for the local orange cultivar under Iraqi environmental conditions, leading farmers to use arbitrary estimates that may result in either excess or deficiency in nutrition.

The main research problem stems from the existing scientific gap between the practical need to improve the quality of local orange fruits on one hand, and the scarcity of local experimental data on the combined interaction of calcium and boron in foliar sprays on the other, which motivated the design of this study with specific factors and concentrations to directly address these questions.

1.2 Research Importance

The importance of this study derives from several aspects:

First: Scientific Importance

This study provides a novel scientific contribution by providing original experimental field data addressing the functional interaction between calcium and boron concentrations when applied as foliar sprays, and their effect on a range of key quality traits of orange fruits. Its importance is highlighted by addressing a clear knowledge gap in the local literature, as most previous studies focused on the individual effects of nutrients, whereas their combined interaction—particularly between calcium and boron—has not been investigated in sufficient depth under local environmental (climatic and edaphic) conditions. The study also contributes to the physiological understanding of the role of these two elements in regulating vital processes associated with fruit formation and quality, such as carbohydrate transport, cell wall stability, and improving the chemical and physical characteristics of the fruits.

Second: Economic Importance

The study gains significant economic importance due to its direct link to improving the quality of horticultural production. Improving quality indicators—such as increasing total soluble solids (TSS), total sugars, vitamin C content, while reducing total acidity, and increasing fruit weight and volume—directly reflects on the market value of the fruits. This improvement enhances the competitiveness of the local product in internal and external markets, allowing for better marketing and export opportunities. It also contributes to increasing the economic return for farmers and reducing losses resulting from low quality, thus supporting the economic sustainability of the agricultural sector.

Third: Health and Nutritional Importance

The importance of the study also stems from its nutritional and health dimension. Improving the chemical content of orange fruits—especially increasing the concentration of vitamin C and natural sugars—enhances their nutritional value as a rich source of antioxidants and elements essential for human health. This aligns with modern global trends focusing on promoting the consumption of functional foods with high health benefits, making the study's results important not only at the agricultural level but also at the level of public health and improving consumer dietary patterns.

Fourth: Applied and Extension Importance

This study provides a robust scientific basis that can be used to formulate practical recommendations for foliar fertilization programs in orange orchards, particularly regarding determining optimal concentrations and application timing for both calcium and boron. Its results also contribute to supporting agricultural extension programs by providing applicable, implementable solutions that can be disseminated to farmers in central and southern regions with similar environmental conditions. This can improve the efficiency of agricultural input use, increase crop productivity and quality, and enhance the integrated management of citrus tree nutrition.

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1.3 Research Objectives

1. To evaluate the effect of different concentrations of calcium and boron (individually and interactively) on the quality traits of local orange fruits.

2. To determine the optimal combination of the two elements that achieves the highest fruit quality levels under Iraqi environmental conditions.

3. To interpret the physiological and biochemical mechanisms of the synergistic interaction between calcium and boron in improving quality traits.

4. To derive applicable recommendations for foliar nutrition programs for local orange trees in Iraq.

III. Materials and Methods

2.1 Site Location and Environmental Conditions

The field experiment was conducted during the 2025 agricultural season in a private local citrus orchard located in the Salman Pak area / Al-Mada'in District / Baghdad Governorate, on the eastern bank of the Tigris River (latitude 33°27' N, longitude 44°34' E, elevation 27 m above sea level). The climate is characterized as dry to semi-dry, with hot summers (average July temperature 44°C) and mild to cool winters (average January temperature 11°C), and an average annual rainfall not exceeding 142 mm. The study included 54 trees, 15 years old, of the local orange cultivar (Citrus sinensis L.) grafted onto sour orange rootstock (Citrus aurantium), spaced at 5×5 m on homogeneous land. The soil was heavy clay, with pH 7.5, EC 1.38 dS m^{-1}, organic matter content of 2.27%, and calcium carbonate content of 17.73%. Soil and water analyses were conducted at the laboratories of the Agricultural Research Center in Al-Za'franiya district according to standard methods. The experimental site is directly relevant to the research problem, as its calcareous, high-pH soil represents the dominant type in Iraqi citrus orchards that suffer from calcium and boron fixation and low root availability, making foliar spray the most viable solution to overcome this limitation.

2.2 Soil and Irrigation Water Properties

Random soil samples were taken from the orchard before applying the treatments at a depth of 0-30 cm, along with a sample of irrigation water. Analyses were conducted at the laboratories of the Agricultural Research Center in Al-Za'franiya / Scientific Research Authority / Ministry of Higher Education and Scientific Research. Their characteristics are shown in Table (1).

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Table (1): Results of soil analysis at the experimental site — Salman Pak area / Al-Mada'in District / Baghdad, 2025

Analytical Trait	unite	Measured Value	Reference Level
Soil reaction (pH)	pH	7.52	6.5 – 8.5 (مقبول)
Electrical conductivity (EC)	$dS\ m^{-1}$	1.38	< 2.0 (غير ملحي)
Calcium carbonate	%	17.73	< 20 (عادي)
Organic matter	%	2.27	2 – 4 (متوسط)
Texture	—	طيني ثقيل	—
Bulk density	$g\ cm^{-3}$	1.28	1.1 – 1.4
Available calcium (Ca)	$mg\ kg^{-1}$	1820	—
Available boron (B)	$mg\ kg^{-1}$	0.42	< 0.5 (ناقص)
Total nitrogen (N)	%	0.09	0.1 – 0.2 (منخفض)
Available phosphorus (P)	$mg\ kg^{-1}$	8.4	5 – 15
Available potassium (K)	$mg\ kg^{-1}$	195	100 – 250

- Analyses were conducted in the laboratories of the Agricultural Research Center / Al-Za'franiya – Scientific Research Authority – Ministry of Higher Education and Scientific Research, according to approved standard methods.

- The available boron value (0.42 $mg\ kg^{-1}$) is below the critical threshold (0.5 $mg\ kg^{-1}$), confirming the need for foliar nutrition.

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Table (2): Results of the analysis of irrigation water used at the experimental site — 2025

Analytical Trait	unite	Measured Value	FAO
Water reaction (pH)	pH	7.38	6.5 – 8.4
Electrical conductivity (EC)	dS m^{-1}	0.87	< 3.0
Total dissolved salts (TDS)	mg L^{-1}	557	< 2000
(Ca^{2+})	meq L^{-1}	3.20	—
(Mg^{2+})	meq L^{-1}	1.85	—
(Na^{+})	meq L^{-1}	2.40	< 9.0
(Cl^{-})	meq L^{-1}	2.10	< 10.0
(SO_4^{2-})	meq L^{-1}	1.75	—
(HCO_3^{-})	meq L^{-1}	3.50	< 8.5
(B)	mg L^{-1}	0.18	< 2.0
(SAR)	—	1.64	< 15

- Analyses were conducted in the laboratories of the Agricultural Research Center / Al-Za'franiya – Scientific Research Authority – Ministry of Higher Education and Scientific Research, according to approved standard methods.

- The values indicate that the irrigation water is of acceptable quality and does not pose a salinity stress on the orange trees.

2.3 Study Factors

The experiment included two factors:

First factor — Calcium spray: Calcium chloride ($CaCl_2$) with 98% purity was used as the calcium source, including three levels:

- Ca_0: Control treatment (distilled water only, no calcium spray).

- Ca_1: Concentration of 100 mg Ca L^{-1} of the prepared solution.

- Ca_2: Concentration of 200 mg Ca L^{-1} of the prepared solution.

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Second factor — Boron spray: Boric acid (H_3BO_3) with 99.5% purity was used as the boron source, including three levels:

- B_0: Control treatment (no boron spray).

- B_1: Concentration of 30 mg B L^{-1} of the prepared solution.

- B_2: Concentration of 60 mg B L^{-1} of the prepared solution.

A spreading-sticking agent (Tween-20) at a concentration of 0.05% was added to all spray solutions to improve spreading and adhesion to the leaf surface.

Link to the research problem: The selection of Ca concentrations (0, 100, 200 mg L^{-1}) and B concentrations (0, 30, 60 mg L^{-1}) was carefully considered to address the deficiency of these two elements in high-pH soil that restricts their root availability, as foliar spraying allows the delivery of the elements directly to fruit tissues without encountering soil obstacles.

2.4 Experimental Design and Statistical Analysis

The experiment was conducted according to a Randomized Complete Block Design (RCBD) as a fully controlled two-factor factorial experiment, with nine treatments (3×3) and three replications (blocks) per treatment. Two trees were allocated per experimental unit, making a total of 54 trees. Treatments were distributed randomly within each replicate to ensure uniform representation of the orchard site conditions. Statistical analysis was performed using Genstat 12th edition software, and the Least Significant Difference (LSD) test at a probability level of 0.05 was used to compare means.

2.5 Spraying Dates and Application Metho

The trees were sprayed on four critical dates corresponding to the physiological stages of fruit development:

- First date:During full flowering (April 2025) — to contribute to improving fruit set through the role of boron in pollen tube growth.

- Second date: Fruit set stage (May 2025) — to enhance fruit cell growth during its division stage.

- Third date: 15 days after fruit set establishment (June 2025) — to support the cell expansion stage and sugar accumulation.

- Fourth date:Six weeks before fruit ripening (September 2025) — to improve final biochemical quality before harvest.

Spraying was carried out in the early morning hours (7:00–9:00 AM) to avoid high heat and ensure optimal absorption of solutions through leaf and fruit surfaces.

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2.6 Studied Quality Traits and Methods Used

Samples were collected upon full fruit ripening (November 2025) by taking 10 random fruits from each experimental unit, representing the four cardinal directions and multiple heights. The following quality traits were estimated:

1. Total Soluble Solids (TSS%): The percentage of total soluble solids in fruit juice was measured using a hand refractometer (0–32% Brix scale), with temperature correction at 20°C.

2. Total Sugars (%): Total sugar percentage was estimated using the phenol-sulfuric acid method described by Dubois et al. (1956), using a spectrophotometer at a wavelength of 490 nm.

3. Total Acidity (TA%): Total acidity was estimated by titration with 0.1N sodium hydroxide (NaOH) solution using phenolphthalein as an indicator. Results were expressed as a percentage of citric acid according to the standard equation.

4. TSS/TA Ratio (Maturity and Palatability Quality Index): Calculated by dividing the TSS value by TA. This ratio is one of the most important indicators of physiological maturity and fruit palatability quality.

5. Vitamin C — Ascorbic Acid (mg 100 mL^{-1}): Vitamin C content was estimated using the dye titration method described by (5) using freshly prepared and standardized 2,6-Dichlorophenol Indophenol dye.

6. Juice Percentage (%): Juice was extracted from whole fruits using a hand juicer after weighing them. Juice percentage was calculated by dividing juice weight by fruit weight and multiplying by 100.

7. Fruit Weight (g): Each fruit weight was measured using a digital balance with 0.01 g accuracy.

8. Fruit Volume (cm^3):Volume was measured using the water displacement method in a graduated cylinder with 5 ml accuracy.

Link to the research problem: The selection of these eight traits is not random; they cover all the biochemical and physical quality indicators directly affected by calcium and boron deficiency, allowing for the measurement of the comprehensive response to addressing the aforementioned nutritional deficiency problem.

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3. Results

3.1 Total Soluble Solids (TSS%)

The results in Table (3) indicate clear significant differences for both calcium and boron factors and their interaction on the percentage of total soluble solids. Regarding the calcium factor alone, the average TSS at Ca_0 (control) was 10.47%, increased to 11.17% at Ca_1, and reached its highest at 11.65% at Ca_2, with a significant difference among the three levels. Regarding boron, the average TSS at B_0 was 10.38%, increased to 11.12% at B_1, and reached 11.78% at B_2. Regarding the interaction of the two factors, the interaction $Ca_2 \times B_2$ was superior with the highest TSS percentage reaching 12.40%, while the interaction $Ca_0 \times B_0$ gave the lowest value of 9.80%, with an absolute difference of 2.60% and a percentage increase of 26.5% between the best and worst treatments.

Table (3): Effect of calcium and boron spraying on total soluble solids (TSS%) of local orange fruits

B \ Ca	Ca_0	Ca_1	Ca_2	Average B
B_0	9.80	10.45	10.90	10.38
B_1	10.50	11.20	11.65	11.12
B_2	11.10	11.85	12.40	11.78
Average Ca	**10.47**	**11.17**	**11.65**	—
LSD 0.05	**n.s**	**0.2126**	**0.3683**	—

3.2 Total Sugars (%)

The results in Table (4) showed significant differences for both factors and their interaction on the percentage of total sugars. The average sugar content at Ca_0 was 5.68%, which increased significantly to 6.18% at Ca_1 and reached 6.53% at Ca_2. Regarding boron, B_0 recorded an average of 5.60%, which increased to 6.15% at B_1 and reached 6.65% at B_2. In the interaction of the two factors, $Ca_2 \times B_2$ recorded the highest percentage of total sugars, reaching 7.10%, compared to 5.20% in the control treatment $Ca_0 \times B_0$, representing an increase exceeding 36.5%.

Table (4): Effect of calcium and boron spraying on total sugars (%) of local orange fruits

B \ Ca	Ca_0	Ca_1	Ca_2	B Average
B_0	5.20	5.65	5.95	5.60
B_1	5.70	6.20	6.55	6.15
B_2	6.15	6.70	7.10	6.65
Ca Average	**5.68**	**6.18**	**6.53**	—
LSD 0.05	**0.0564**	**0.0564**	**n.s**	—

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3.3 Total Acidity (TA%)

The results in Table (5) show that calcium and boron spraying resulted in a significant progressive decrease in the total acidity percentage with increasing concentrations. Ca_0 recorded the highest average acidity (0.88%), while it decreased to 0.79% at Ca_1 and reached its lowest at 0.72% at Ca_2. Regarding boron, B_0 recorded an average of 0.89%, which decreased to 0.79% at B_1 and reached 0.72% at B_2. The interaction $Ca_2 \times B_2$ gave the lowest total acidity percentage, reaching 0.65%, compared to 0.98% at $Ca_0 \times B_0$, a relative decrease of 33.7%.

Table (5): Effect of calcium and boron spraying on total acidity (TA%) of local orange fruits

B \ Ca	Ca_0	Ca_1	Ca_2	Average B
B_0	0.98	0.88	0.80	0.89
B_1	0.87	0.78	0.72	0.79
B_2	0.79	0.72	0.65	0.72
Ca Average	**0.88**	**0.79**	**0.72**	—
LSD 0.05	**0.02069**	**0.02069**	**0.03584**	—

3.4 Vitamin C Content (mg 100 mL^{-1})

The results in Table (7) showed a significant progressive increase in juice vitamin C content in response to increasing calcium and boron concentrations. The average vitamin C at Ca_0 was 46.33 mg 100 mL^{-1}, which increased to 50.17 at Ca_1 and reached 53.63 at Ca_2. Regarding boron, B_0 recorded an average of 45.63 mg, which increased to 49.93 at B_1 and reached 54.57 at B_2. The interaction $Ca_2 \times B_2$ was superior with the highest value reaching 58.90 mg 100 mL^{-1}, compared to 42.50 in the control treatment, representing an increase of 38.6%.

Table (7): Effect of calcium and boron spraying on vitamin C (mg 100 mL^{-1}) of local orange fruits

B \ Ca	Ca_0	Ca_1	Ca_2	Average B
B_0	42.50	45.80	48.60	45.63
B_1	46.30	50.10	53.40	49.93
B_2	50.20	54.60	58.90	54.57
Ca Average	**46.33**	**50.17**	**53.63**	—
LSD 0.05	**0.3922**	**0.3922**	**0.6794**	—

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3.5 Juice Percentage (%)

The results in Table (8) indicate a significant increase in juice percentage with increasing calcium and boron concentrations. The average juice percentage at Ca_0 was 40.83%, which increased to 43.40% at Ca_1 and reached 45.63% at Ca_2. Regarding boron, B_0 recorded an average of 40.30%, which increased to 43.33% at B_1 and reached 46.23% at B_2. The interaction $Ca_2 \times B_2$ achieved the highest juice percentage, reaching 49.10%, compared to 38.50% in the control treatment, with an absolute increase of 10.60%.

Table (8): Effect of calcium and boron spraying on juice percentage (%) of local orange fruits

B \ Ca	Ca_0	Ca_1	Ca_2	Average B
B_0	38.50	40.30	42.10	40.30
B_1	40.80	43.50	45.70	43.33
B_2	43.20	46.40	49.10	46.23
Ca Average	**40.83**	**43.40**	**45.63**	—
LSD 0.05	**1.271**	**1.271**	**n.s**	—

3.6 Fruit Weight (g) and Fruit Volume (cm³)

The results in Table (9) show significant differences in both fruit weight and volume in response to calcium and boron spraying. Regarding weight, the average fruit weight at Ca_0 was 158.5 g, increasing to 173.2 g at Ca_1 and reaching 187.6 g at Ca_2. Regarding boron, B_0 recorded an average of 160.5 g, increasing to 173.1 at B_1 and reaching 185.7 at B_2. Regarding volume, the average at Ca_0 was 198.8 cm^3, increasing to 217.7 at Ca_1 and reaching 236.8 at Ca_2. The interaction $Ca_2 \times B_2$ achieved the highest fruit weight (202.6 g) and largest volume (256.0 cm^3), compared to the lowest values of the control treatment $Ca_0 \times B_0$ (148.5 g, 185.0 cm^3), representing an increase of 36.4% in weight and 38.4% in volume.

Table (9): Effect of calcium and boron spraying on fruit weight (g) and volume (cm³) of local orange cultivar

B \ Ca	Ca_0 Weight	Ca_1 Weight	Ca_2 Weight	Ca_0 Volume	Ca_1 Volume	Ca_2 Volume
B_0	148.5	160.2	172.8	185.0	200.5	218.0
B_1	158.3	173.5	187.4	198.5	218.0	236.5
B_2	168.7	185.9	202.6	213.0	234.5	256.0
Ca Average	**158.5**	**173.2**	**187.6**	**198.8**	**217.7**	**236.8**
LSD 0.05	**9.38**	**9.38**	**n.s**	**2.749**	**2.749**	**4.762**

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4. Discussion of Results

4.1 Discussion of Total Soluble Solids (TSS%) The notable improvement in the percentage of total soluble solids in response to calcium spraying is attributed to several physiological mechanisms; calcium enhances cell membrane stability by forming pectate bonds with carboxyl groups of galacturonic acid in cell walls, thereby reducing membrane permeability and slowing down metabolic processes that deplete sugars, in addition to inhibiting the activities of degradative enzymes such as amylase and invertase that break down accumulated sugars in fruits (3; 6). This is complemented by the role of boron in regulating the transport of carbohydrate materials from their production sites in leaves to their storage sites in fruits via the phloem, as boron forms complexes with transported sugars (mannitol-borate) that facilitate the flow (4). The synergy between the two elements also contributes to enhancing overall carbohydrate metabolism and the accumulation of soluble sugar substances in fruits (7). The results of the present study are consistent with those of (8), who documented a similar increase in TSS with combined calcium and boron spraying on Valencia orange.

4.2 Discussion of Total Sugars (%) The positive effect of calcium and boron on total sugar percentage is linked to interrelated mechanisms; calcium contributes to reducing the cellular respiration rate by inhibiting the activity of certain Krebs cycle enzymes, thereby maintaining a higher balance of accumulated sugars in fruits and extending their shelf life (6). On the other hand, boron facilitates the transport of carbohydrate materials from leaves to fruits via the phloem by forming transportable sugar-borate complexes, which increases the flow of sugars towards the fruits and maximizes their accumulation (9). The results of the present study are consistent with those demonstrated by (10) in their study on pomegranate, where they found a notable increase in total sugar percentage when spraying with nano-calcium and nano-boron.

4.3 Discussion of Total Acidity (TA%) The decrease in total acidity in response to calcium spraying is explained by its role in regulating the metabolism of organic acids, especially citric acid which is predominant in orange fruits; calcium contributes to inhibiting the activity of the enzyme aconitase responsible for converting citrate to isocitrate in the Krebs cycle, thus reducing the accumulation of acidity in fruits. Additionally, calcium converts part of the organic acids into insoluble calcium salts in the juice (6). Boron deepens this effect by directing metabolized carbon towards sugars instead of organic acids. (7) demonstrated similar results on strawberries, and these results also agree with those observed by (11) of a decrease in total acidity when using calcium chloride in foliar sprays on strawberries.

4.4 Discussion of Vitamin C The increase in vitamin C content in fruit juice in response to calcium and boron spraying reflects a positive effect on ascorbic acid biosynthesis pathways and its stability maintenance. Calcium reduces the activity of the enzyme ascorbate oxidase responsible for the oxidation and breakdown of vitamin C, thereby maintaining higher concentrations of it in the fruits (12). Furthermore, boron activates the biosynthetic pathways of ascorbic acid by enhancing the activity of the enzyme L-galactono-1,4-lactone dehydrogenase, which represents the final step in the synthetic sequence of vitamin C in the plant cell. A study by (13) on pomegranate demonstrated similar results, and the findings also agree with those observed by (4) of a notable improvement in vitamin C when spraying calcium and boron together on citrus.

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4.5 Discussion of Juice Percentage Results

The improvement in juice percentage is attributed to calcium's role in regulating osmotic pressure and enhancing water absorption through roots and its flow towards juice sac cells during the cell division and expansion stages. Calcium also contributes to maintaining the integrity of the membranes of juice vesicle cells, thereby reducing water leakage and cell shrinkage (3). Regarding boron, it improves fruit set and reduces premature fruit drop, thereby extending the duration of fruit growth and development and maximizing juice accumulation within them (14). These results agree with those found by (15) of an increase in juice percentage when applying boric acid to sweet orange.

4.6 Discussion of Fruit Weight and Volume Results

The increase in fruit weight and volume is among the indicators most closely associated with market value and consumer requirements. Calcium's effect on increasing fruit size is linked to its pivotal role in activating fruit cell division during the early fruit set stage and their subsequent expansion; calcium is necessary for activating calcium-dependent protein kinases (CDPKs) and cell division signal transduction pathways. It also establishes mechanical strength for cell walls through the formation of calcium pectates, creating a more robust cellular structure capable of retaining water and solutes (16). Regarding boron, it enhances fruit set and reduces premature fruit drop by improving pollen tube growth and ovule fertilization, resulting in more complete fruits with higher weight (15). These results are consistent with those observed by (4) on citrus and those demonstrated by (16) on mandarin of a notable increase in weight and size when applying calcium fertilization programs.

5. Conclusions and Recommendations

IV. Conclusions

1. Foliar spraying with calcium and boron had a significant positive effect on all studied quality traits of local orange fruits (TSS, total sugars, TSS/TA, vitamin C, juice percentage, fruit weight, fruit volume) and a significant negative (desirable) effect on total acidity (TA).

2. The interaction $Ca_2 \times B_2$ (200 mg Ca L^{-1} + 60 mg B L^{-1}) achieved the highest values for all improved quality traits and the lowest value for total acidity, representing the optimal choice for foliar spraying under Iraqi environmental conditions.

3. A clear synergistic effect between calcium and boron in improving fruit quality, surpassing the effect of each individually, is achieved, confirming the importance of combining the two elements in foliar nutrition programs.

4. The study results confirm that foliar spraying represents the most effective solution to overcome the constraints of calcareous, high-pH soil that restricts the root availability of calcium and boron, directly linking the experimental protocol followed to the diagnosed research problem.

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5.2 Recommendations

1. It is recommended to include a foliar spraying program with a concentration of 200 mg Ca L^{-1} together with 60 mg B L^{-1} within the agricultural service package for local orange orchards in Iraq, distributing the spray over four critical dates (flowering, fruit set, 15 days after fruit set, and six weeks before ripening).

2. It is recommended to conduct complementary studies addressing: the effect of optimal concentrations on post-harvest storage traits, a comparison between different sources of calcium and boron, and generalizing the experiment to other geographical regions.

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