The Future of Applied Science

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Productivity and Fruit Quality of Balady Lime Trees in Relationship to Spraying Iron, Zinc and Boron

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https://doi.org/10.37229/fsa.fjas.2026.01.22

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Future Science Association

Available online free at
www.futurejournals.org

Print ISSN: 2767-178X

Online ISSN: 2767-181X

Received: 20 November 2025
Accepted: 5 January 2026
Published: 22 January 2026

Publisher's Note: FA stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: The present investigation was carried out during two successive seasons 2023 and 2024 on ten years Balady lime trees, grown in Malawi district El-Minia Governorate, where the soil texture was sandy, since water table depth is not less than two meters. The orchard was irrigated throw drip irrigation system. The chosen trees were planted at 4 X 5 meters apart. This investigation further highlights the importance of spraying iron, zinc, and boron on the yield and fruit quality of Balady lime trees grown under sandy soil and salinity stress conditions. The results clearly showed that spraying Balady lime trees with the three micronutrients (Fe, Zn and B) at 100 & 200 ppm, either singly or in combination, significantly enhanced the yield and fruit physicochemical properties of Balady lime trees compared to untreated trees. However, spraying Boron individually was more effective than spraying Fe or Zn on the the different examined properties. Furthermore, the combined treatment with 200 ppm Fe, 200 ppm Zn and 200 ppm B recorded the best results on the yield and fruit physical and chemical properties, during the two experimental seasons respectively.

Key words: Balady Lime trees, micronutrients, sandy soil, yield, and fruit quality.

1. Introduction

It is well known that Balady lime (*Citrus aurantifolia* Swingle) conceder as one of the most important citrus crop in Egypt in terms of export value and local consumption. In 2024, the cultivated area reached approximately 108,500 feddans, producing about 425,000 tons, of which more than 95,000 tons were exported with a value exceeding ≈ 165 million US$ (**Ministry of Agriculture, Egypt, 2025 and FAO, 2024**). However, more than 70% of this area is located in newly reclaimed lands suffering from soil and irrigation water salinity ranging between 3–7 dS m^{-1} and high pH (7.8 to 8.8). These stressful conditions drastically reduce the availability and uptake of micronutrients (Fe, Zn, B) by 40 – 75%, leading to severe deficiency symptoms, poor flowering, excessive fruit drop, and a sharp decline in yield from 35 – 45 t/feddan in old valley lands to only 18 – 25 t/feddan in saline areas (**El-Kassas *et al.*, 2013; Habasy *et al.*, 2021 and Srivastava & Singh, 2022**). Lemon trees in Egyptian soils face several challenges related to soil fertility and nutrient deficiencies, particularly in trace elements such as iron, zinc, and boron.

Iron is an essential micro-nutrient, it playing a vital role in chlorophyll synthesis, photosynthesis, and enzymatic activity, which directly influence growth and yield of native lemon tree. In sandy soils, iron availability is often limited due to low organic matter, high pH, and rapid leaching, this leading to iron chlorosis and reduced productivity in lemon orchards (**Marschner, 2012**). Under salinity stress, iron contributes to maintaining cellular metabolism and antioxidant defense systems, helping lemon tree mitigate oxidative damage caused by excess salts (**Rout and Sahoo, 2015)**. Boron playing a crucial role in cell wall formation, membrane integrity, carbohydrate translocation, and reproductive development in lemon trees. In desert soils, boron deficiency is common due to low organic matter, poor nutrient retention, and limited biological activity, which negatively affect growth and productivity of lemon orchards (**Marschner, 2012**). Boron is also involved in sugar transport and hormonal regulation, which are critical for fruit development and yield formation under arid conditions (**Brown *et al.*, 2008**). In sandy desert soils, proper B fertilization, especially through foliar application, improves nutrient balance and overall tree performance (**Tripathi *et al*., 2018; Wojcik 2003 and Silva e*t al.*, (2022).** Zinc (Zn) is an essential micro-nutrient required for normal growth, metabolism, and productivity of citrus trees, as it plays a key role in enzyme activation, protein synthesis, and auxin (IAA) formation. In new reclamation desert soils, zinc deficiency is widespread due to high soil pH, low organic matter content, calcareous nature, and limited zinc availability, leading to poor vegetative growth and reduced yield in citrus orchards (**Cakmak 2000; Marschner, 2012 and Tahir *et al.*, 2020)**. However, adequate zinc nutrition improves leaf expansion, chlorophyll formation, and photosynthetic efficiency, which are critical for sustaining growth of citrus trees under arid conditions (**Srivastava & Singh, 2022**). Zn is also involved in carbohydrate metabolism and reproductive development, contributing to improved flowering, fruit set, and fruit retention in citrus species (**Cakmak 2000, Wojcik, 2001 and Alloway, 2008**). Therefore, proper zinc management is a vital component of balanced nutrition programs for citrus trees cultivated in desert environments.

The current study further highlights the importance of spraying iron, zinc, and boron on yield and fruit quality of Balady lime trees grown under sandy soil and salinity stress conditions.

2. Material and Methods

The present investigation was carried out during two successive seasons 2023 and 2024 on sixteen uniforms in vigor ten years Balady lime trees. The chosen trees were grown in privet orchard located at Drawe Village Malawi district Minia Governorate, where the soil texture was sandy, since water table depth is not less than two meters. The orchard was irrigated throw drip irrigation system. The chosen trees were planted at 4 X 5 meters apart.

2.1. Soil and water analysis

Samples of soil and water were collected and laboratory analyzed according to **Ward and Johnston (1962) and Wilde *et al.* (1985).** The physical and chemical analysis of soil and water are illustrated in Table (1).

2.2. Experimental work

In order to justify the effect and the suitable dose of iron, zinc and boron each on Balady lime trees productivity and fruit at two concentrations (100 and 200 ppm) productivity and fruit quality of Balady lime trees during 2023 and 2024 seasons; Fe in form of ferrous sulphate ($FeSO_4$), Zn in form of zinc sulphate ($ZnSO_4$), and B in form of boric acid (H_3BO_3) were sprayed at 100 & 200 ppm. All treatments were sprayed three times the first one at Early February, the second at Early April and last one at Early May. The experiment involved the following nine treatments from the three micronutrients and control, as follow the nine treatments were arranged: Control (trees sprayed with water); spraying Fe at 100ppm; spraying Fe at 100ppm; spraying Zn at 100 ppm; spraying Zn at 200 ppm; spraying B at 100 ppm; Spraying B at 200 ppm. Each treatment was replicated four times, one tree per each replicate. Triton B was used as a wetting agent; it was added to all spraying solutions at 0.01%.

Table (1). Physical and chemical analysis of experiment orchard soil and the water used in irrigation

Soil analysis		Water analysis	
Constituents	**Values**	**Constituents**	**Values**
Sand %	82.2	**E.C (mmhos/cm/25C)**	2.2
Silt %	8.8	**Hardness**	13.2
Clay %	7.0	**pH**	8. 1
Texture	Sandy	**Ca (mg/L)**	49.4
EC (1:2.5Extract) mmhos/cm/ 25 C	2.1	**Mg (mg/L)**	22.7
Organic matter %	0.09	**K (mg/L)**	12. 2
pH (1 : 2.5 extract)	8.2	**Na (mg/L)**	66.1
Active lime %	8.3	**Sum of Cations (mg/L)**	9.16
N %	0.03	**Alkalinity (mg/L)**	137
Phosphorus (ppm)	42	**Chlorides (mg/L)**	119
Available Ca (meq/100g)	0.78	**Nitrate (mg/L)**	6.2
C/N Ratio	17.07	**Sum of anions (mg/L)**	6.72

2.3. Experimental design and Statistical analyses

The experiment was performed by using a randomized complete block design (RCBD), and statistical analyses were performed with SPSS program. The data were analyzed by one-way ANOVA, means of the treatments were compared by using LSD test, at 0.05 (**Sendecor and Cochran, 1990**).

2.4. Determination of different characteristics

The following characteristics were assessed during the two experimental seasons.

Yield and its component: The fruits were harvested when the color start to turn on yellow and the juice % arrive to 30% (w/w), according to **Martin-Préval, *et al.* (1984) Ibrahim (2010)**. The yield per tree (kg/tree) was calculated mathematically by multiplying the number of fruits per tree by the average fruit weights (g). Twelve fruits were randomly collected from the four main sides of the tree at a height equal to half the height of the tree at maturation stage. These fruits were used for determined the physical and chemical properties of fruits.

Fruit physical properties: Average fruit weight (g), were done by using sensitivity balance with 0.01g accuracy. Average fruit length without neck (cm) and average fruit diameter (cm) were done by using vernier caliper with 0.01cm accuracy. Determination of fruit peel thickness (mm) and average fruit pulp diameter (cm) by using vernier caliper with 0.01cm accuracy.

Fruit chemical properties: Percentage of total soluble solids (T.S.S %) were determined in juice were obtained from each replicate, by using a hand refractometer at 20 ºC, and the results were expressed as a percentage (Brix), according to **Ranganna (1990)**. Percentage of titratable acidity (TA), expressed in grams citric acid per 100 grams juice were done by titration against with 0.1 N NaOH, using 1 ml diluted juice in 10 ml distilled water, and the results expressed in gram citric acid / 100 g of fresh juice (According to **A.O.A.C 2000)**. Then, the TSS/acidity ratio was calculated. Vitamin C in lime juice was determined by volumetric titration method, using 2,6-Dichlorophynol Endophynol Pigment, according to **Ranganna (1990)**.

4. Results and Discussion

4.1. Effect on yield and its component

The data presented in Table (2) clearly indicate that spraying Balady lime trees with the three micronutrients (Fe, Zn and B) at 100 & 200 ppm, either singly or in combination, significantly affected fruit yield, number of fruits per tree and average fruit weight of Balady lime trees grown in sandy soil, during the two experimental seasons (2023 and 2024), as compared with the untreated trees control.

4.1.1. Effect on yield (kg/tree)

It is clear from Table (2) that spraying seaweed, Fe, Zn, and B individually was capable to enhancing the yield (kg/tree) during the two experimental seasons. However, spraying Boron at 200 ppm present the best results 26.5 at 27.1 kg/tree in this respect, during the two seasons respectively. However, the combined treatment of Fe at 200 ppm + Zn at 200 ppm + B at 200 ppm produced the highest yield (29.2 and 30.5 kg/tree) in 2023 and 2024 seasons, respectively. The second-best treatment was spraying the combination of Fe 100 ppm + Zn 100 ppm + B 100 ppm, with yields of 28.0 & 29.3 kg/tree. On the other hand, the control treatment recorded the lowest yield (21.1 and 21.7 kg/tree).

4.1.2. Number of fruits per tree

Similar results were obtained according to the number of fruit per tree, as shown in Table (2). Spraying the three examined micronutrients at two concentrations were capable to increasing the number of fruits / tree significantly, in compared to untreated trees (control). Furthermore, the highest number of fruits per tree was obtained by the combined treatment with (Fe + Zn + B) at higher concentration (200 ppm), reaching (863.5 and 870.2 fruits/tree), followed by the combined low concentration treatment. While, the control trees produced the lowest number of fruits per tree (743.3 and 755.7), during the two experimental seasons respectively.

4.1.3. Average fruit weight (g)

Data illustrated in Table (2) showed the response of Balady lime trees grown in sandy soil to spraying Fe (at 100 and 200 ppm), Zn (at 100 and 200 ppm, and B (at 100 and 200 ppm). It is clear from this table that spraying each micronutrient individually was capable to improve Balady lime fruit (g) in both experimental seasons. However, spraying B at 200 ppm showed more effective (33.1 and 34.9) rather than spraying Zn or Fe. These findings were true during the two experimental seasons. Furthermore, treated the trees with the three micro-nutrients in combination at higher concentrations (200 ppm) resulted in the heaviest fruits (38.0 and 36.9 g), followed by the combined treatments low concentration “Fe, Zn, and B at 100 ppm for each one”, it recorded 36.8 and 33.5 g fruit weight, in both season respectively. While, the same table demonstrated that the control trees recorded the lowest fruit weight (24.4 and 25.1 g) in both experimental seasons.

The improvement in yield and fruit characteristics can be attributed to the synergistic effects micronutrients. However, Fe, Zn and B improve enzymatic activity, carbohydrate accumulation and hormonal balance, resulting in increased fruit set, growth and weight (**Lindsay & Schwab 1982; Pantnagar 2020 and Lovatt 2009**). The increase in total yield reflects the cumulative positive effects of treatments on all stages of fruit growth and development. Combined treatments with the three micronutrients improved flowering, fruit set, and vegetative growth, resulting in higher yield. **Alva *et al.* (2006)** proved that a balanced fertilization program that includes micronutrients increases citrus tree yield by 20-35%. Zinc and boron are essential for fruit growth and development. Zinc participates in auxin synthesis that regulates cell division in developing fruit, while boron is necessary for sugar transport to fruits. **Lovatt (2009)** clarified that zinc and boron deficiency leads to small fruit size and reduced yield in citrus. Iron enhances photosynthesis, providing the carbohydrates necessary for fruit growth. Iron deficiency causes leaf yellowing and decreased photosynthetic efficiency, negatively reflecting on fruit size and weight. **Pestana *et al.* (2003)** confirmed that treating iron deficiency in citrus trees led to a 15-25% increase in individual fruit weight.

Table (2). Effect of spraying Fe, Zn and B on yield (kg/tree), fruit numbers/tree, and fruit weight (g) of Balady Lime, during 2023 and 2024 seasons

Treatments	Yield (kg/tree)		No. of fruit / tree		Fruit weight (g)	
	2023	2024	2023	2024	2023	2024
Control	21.1	21.7	743.3	755.7	24.4	25.1
Fe 100 ppm	23.0	24.6	787.7	792.4	29.2	31.1
Fe 200 ppm	24.7	24.9	802.6	809.5	30.7	30.8
Zn 100 ppm	25.6	26.2	793.9	795.8	32.3	32.9
Zn 200 ppm	26.6	27.5	802.5	812.5	33.1	34.9
B 100 ppm	26.2	26.5	812.3	821.7	32.3	32.2
B 200 ppm	26.5	27.1	819.9	833.7	32.7	32.5
Fe + Zn + B (at 100ppm)	28.0	2٩.٣	83٠.2	840.4	36.8	35.0
Fe + Zn + B (at 200ppm)	29.2	30.5	863.5	870.2	38.0	36.9
Mean	25.6	26.5	805.2	814.6	32.2	35.9
New LSD at 5%	2.1	2.2	29.1	30.3	1.2	1.3

4.2. Effect on fruit physical properties of Balady lime

4.2.1. Effect on fruit volume, fruit dimensions

The data presented in Table (3) showed the effect of spraying Fe, Zn, and B individually or in combination on fruit volume and dimensions of Balady lime grown in sandy soil, during 2023 and 2024 seasons. It is clearly indicating that spraying Balady lime trees with Fe, Zn and B, either singly or in combination, significantly affected fruit volume, length and diameter during the two experimental seasons compared with the untreated trees (control).

A. Fruit volume (cm^3)

It is clear from the obtained data (Table 3) that spraying the three examined micronutrients individually was capable to enhance the fruit volume of Balady lime during the experimental seasons. However, spraying Boron at a 200 ppm had the best effect compared to Zn and Fe individually. The combined treatment with 200 ppm Fe, 200 ppm Zn and 200 ppm B recorded the largest fruit volume (26.09 and 27.76 cm^3), followed by the same combined with low concentration treatment (Fe 100 ppm + Zn 100 ppm + B 100 ppm), which recorded 25.20 and 26.91 cm^3. On the opposite side, the control trees produced the smallest fruits (19.50 and 20.42 cm^3), during the two experimental seasons respectively.

B. Fruit length (cm)

The obtained results showed that spraying the three micronutrients individually significant enhanced the lime fruit length (cm) during the two experimental seasons. Furthermore, spraying Zn at 200 ppm individually showed superior than spraying Fe, B, and seaweed, whereas the fruit length reached 4.51 and 4.55 cm, in both seasons respectively. Furthermore, the combined application of the three micronutrients showed more effective than spraying each one alone. The combined application with high concentration treatment (200 ppm Fe + 200 ppm Zn + 200 ppm B) produced the longest fruits (4.66 and 4.71 cm), while the combined low concentration treatment (100 ppm Fe + 100 ppm Zn + 100 ppm B) recorded slightly shorter fruits (4.56 and 4.62 cm). On the other hand, untreated trees (Control) produced the shortest fruits (4.01 and 4.03 cm), during the experimental seasons respectively.

C. Fruit diameter (cm)

The results presented in Table (3) showed that, spraying the three micro-nutrients had a positive effect on improving fruit diameter. In this regard, the obtained results indicated that the combined treatment with the three micronutrients was superior to treatment with either one alone. The largest fruit diameter was recorded by the combined high concentration treatment (4.11 and 4.22 cm), followed by the combined low concentration treatment (4.02 and 4.15 cm). On the other side, the control treatment produced the smallest diameter (3.49 and 3.44 cm) in both experimental seasons respectively.

The enhancement in fruit volume and dimension is linked to improved photosynthetic activity, nutrient availability and hormonal regulation induced by the combination of the three micronutrients. The integrated application promotes cell division, enlargement, and water and carbohydrate accumulation in developing fruits, resulting in higher volume, length and diameter (**Swietlik & Fang 2009; Taiz *et al.*, 2015 and Habasy *et al.*, 2021**). Iron enhances photosynthesis, increasing carbohydrate flow to developing fruits. Iron deficiency reduces photosynthesis rate and limits sugar availability for fruits. **Molassiotis *et al.* (2006)** confirmed that treating iron deficiency in orange trees improved fruit size and quality noticeably.

The increase in fruit size reflects the positive effect of treatments on fruit cell division and expansion. Auxins produced with zinc assistance, and cytokinins present in seaweed extracts, work together to enhance cell division during early stages of fruit growth. Boron is essential for sugar transport from leaves to developing fruits. Fruits act as a strong sink for carbohydrates, and boron facilitates this transport through phloem. **Helal *et al.* (2019)** found that boron deficiency impedes sucrose transport, leading to small-sized fruits of low quality. Zinc plays a role in auxin hormone synthesis that regulates cell expansion and water accumulation in fruit. **Alloway (2008)** clarified that zinc is essential for tryptophan synthetase enzyme responsible for tryptophan synthesis, the basic precursor of auxin.

Table (3). Effect of spraying Fe, Zn, and B on fruit volume (cm^3), fruit length (cm), and fruit diameter (cm) of Balady Lime, during 2023 and 2024 seasons

Treatments	Fruit volume (cm^3)		Fruit length (cm)		Fruit diameter (cm)	
	2023	2024	2023	2024	2023	2024
Control	19.50	19.52	4.01	4.03	3.49	3.44
Fe 100 ppm	21.12	21.99	4.28	4.31	3.67	3.75
Fe 200 ppm	22.81	23.19	4.22	4.29	3.71	3.79
Zn 100 ppm	23.55	24.12	4.31	4.38	3.81	3.89
Zn 200 ppm	23.89	24.70	4.51	4.55	3.91	3.99
B 100 ppm	24.23	25.19	4.31	4.33	3.78	3.89
B 200 ppm	24.01	24.64	4.39	4.38	3.91	4.04
Fe + Zn + B (at 100ppm)	25.20	26.91	4.56	4.62	4.02	4.15
Fe + Zn + B (at 200ppm)	26.09	27.76	4.66	4.71	4.11	4.22
Mean	23.38	24.79	4.41	4.44	3.82	3.91
New LSD at 5%	2.1	2.6	0.08	0.07	0.08	0.09

4.2.2. Effect on peel thickness, pulp thickness and juice %

The data presented in Table (4) showed the response of peel thickness (mm), pulp thickness (mm) and juice % of Balady lime trees, grown under sandy soil conditions, to spraying Fe, Zn, and B at 100 & 200 ppm. The obtained results clearly indicate that spraying Balady lime trees with the three micronutrients (Fe, Zn and B), either singly or in combination, significantly affected pulp thickness and juice percentage during the two studied seasons.

A. Peel thickness (cm)

It is clear from Table (4) that Peel thickness was slightly and non-significant influenced by foliar spraying with micron nutrients, all treatments failed to varying the thickness of peel significantly, neither in the first season nor in the second one.

B. Pulp thickness (cm)

Data listed in Table (4) showed that spraying the three examined micro-nutrients individually significantly improved the thickness of fruits pulp in both seasons. Whereas, spraying B showed more effective rather than the other micro-nutrients individually or control trees. However, the fruits of trees sprayed with B at 200 ppm recorded 3.58 and 3.62 cm, during 2023 and 2024 seasons respectively. Furthermore, the combined treatment with Fe at 200 ppm, Zn 200 ppm, and B 200 ppm recorded the best thickest of fruit pulp (3.73 and 3.82 cm), followed by the combined low concentration treatment (3.69 and 3.79 cm). On the contrary, Control trees had the thinnest fruit pulp (3.16 and 3.11 cm). These finding were true during the two experimental seasons respectively.

C. Juice percentage (%)

The results listed in Table (4) clearly show that spraying the aforementioned treatments (Fe, Zn, and B) at 100 & 200 ppm played an effective role in improving the juice content of Balady lemons, during the two experimental seasons. the results declared that spraying each micro-nutrient individually was capable to enhancing the Balady lime fruit juice %. However, spraying B at 200 ppm was superior to the other individual treatments, it presented 40.9% and 41.7%. Furthermore, the highest juice percentages were obtained when the trees received the combined treatments (Fe + Zn + B) at 200 ppm (42.9 and 43.7%), followed by the combined with low concentration (42.1 and 42.7%). Contrary control (untreated trees) recorded the lowest juice content (33.2 and 33.4%).

Table (4). Effect of spraying Seaweed extract, Fe, Zn, and B on peel thickness (cm), pulp thickness (cm), and juice % of Balady Lime, during 2023 and 2024 seasons

Treatments	Peel thickness (cm)		Pulp thickness (cm)		Juice %	
	2023	2024	2023	2024	2023	2024
Control	0.32	0.33	3.16	3.11	33.2	33.4
Fe 100 ppm	0.34	0.33	3.33	3.22	37.9	38.2
Fe 200 ppm	0.34	0.34	3.37	3.45	37.7	36.9
Zn 100 ppm	0.33	0.35	3.48	3.55	35.6	36.4
Zn 200 ppm	0.35	0.34	3.43	3.65	37.1	37.9
B 100 ppm	0.35	0.34	3.55	3.61	39.1	40.5
B 200 ppm	0.33	0.34	3.58	3.62	40.9	41.7
Fe + Zn + B (at 100ppm)	0.34	0.31	3.69	3.79	42.1	42.7
Fe + Zn + B (at 200ppm)	0.32	0.33	3.73	3.82	42.9	43.5
Mean	0.33	0.33	3.48	3.54	38.5	39.0
New LSD at 5%	NS	NS	0.30	0.32	2.2	3.1

The increase in juice percentage is considered one of the most important quality indicators for citrus fruits, especially in varieties used for juice. High juice percentage reflects better development of juice vesicles and greater accumulation of water, minerals, vitamins, and acids. **Albrigo (1977)** proved that juice percentage is significantly affected by balanced mineral nutrition, especially potassium and boron. Boron plays a pivotal role in sugar transport to juice vesicles and their development. Boron is necessary for cell wall formation and vesicle expansion. **Shorrocks (1997)** found that boron improves cell membrane permeability and facilitates fluid accumulation in juice vesicles. Zinc and iron enhance photosynthesis and carbohydrate production that is transported to fruits and accumulated in juice vesicles. **Embleton *et al.* (1973)** proved that zinc deficiency reduces sugar content in juice and lowers juice percentage in orange fruits.

On the other side, the absence of significant differences in peel thickness among treatments is considered positive from a commercial perspective, as increased pulp thickness and juice percentage without a corresponding increase in peel thickness means improved edible portion ratio. **Kader and Yahia (2011)** indicated that the optimal ratio between pulp and peel determines the commercial value of citrus fruits.

4.4. Effect on fruit chemical properties of Balady lime

Data presented in Table (5) showed the effect of spraying Fe, Zn, and B at 100 & 200 ppm on Balady lime fruit chemical properties. The obtained results clearly indicate that spraying Balady lime trees with Fe, Zn and B, either singly or in combination, significantly affected fruit chemical properties of lime fruit (TSS %, total acidity % and vitamin C contents), during the two experimental seasons (2023 and 2024).

A. Total soluble solids (TSS%)

The obtained results revealed that, all treatments, individually or in combination, exerted a significant effect on TSS%, during the two experimental seasons. It is clear that, spraying Balady lime trees with the three micro-nutrients in combination at 200 ppm have an announced and significant higher effect on TSS values (12.4 and 12.6%) compared to other treatments or control one, followed by the combined low concentration (Fe at 100 ppm, Zn at 100 ppm and B at 100 ppm) treatment, which presented 11.9 and 12.1%. on the opposite side the control trees presented the minimized TSS values (7.9% and 8.1%). These data were true during the two experimental seasons respectively.

B. Total acidity (%)

The results pertaining to the effect of spraying Fe, Zn, and B as a individually or in combination on total acidity of Balady lime fruits during both experimental seasons revealed that, all treatments of the three examined micronutrients, individually or in combination, was capable to decrease the total acidity of Balady lime fruits, during the two experimental seasons. It is clear from the obtained results spraying Boron at of 200 ppm alone resulted in the lowest acidity (6.61 % and 6.49 %) in the fruit compared to spraying other micro-nutrients each one allone, in both experimental. Furthermore, spraying Balady lime trees with the three micro-nutrients in combination at higher concentration (at 200 ppm) have an announced and significant lower total acidity values (6.09 and 6.02 %) compared to other treatments or control one, followed by the combined low concentration (Fe, Zn, and B at 100 ppm) treatment, which presented 6.12 and 6.11%. On the opposite side the control trees presented the maximized total acidity values (7.54 % and 7.49 %). These findings were true during the two experimental seasons respectively.

C. Vitamin C (mg/100 g FW)

The results pertaining to the effect of spraying Fe, Zn, and B at 100 and 200 ppm as a single or in combination on vitamin C contents of Balady lime fruits during the two experimental seasons. It is clear from the obtained results in Tables (5) that, spraying Balady lime trees with the three micro-nutrients in combination (at 200 ppm) have an announced and significant higher effect on vitamin C values (48 and 48 mg/100 g FW) compared to other treatments or control one, followed by the combined low concentration (Fe at 100 ppm + Zn at 100 ppm + B at 100 ppm) treatment, which presented 43 and 47 mg/100 g FW. On the opposite side the control trees presented the minimized TSS values (26 and 23 mg/100g FW). These data were true during the two experimental seasons respectively.

Table (5). Effect of Fe, Zn, and B on fruit chemical properties of Balady Lime, during 2023 and 2024 seasons

Treatments	TSS %		Total acidity %		V.C. (mg/100g FW)	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**
Control	7.9	8.1	7.54	7.49	26	23
Fe 100 ppm	10.7	10.6	7.11	7.01	37	33
Fe 200 ppm	10.9	11.0	7.05	6.98	35	38
Zn 100 ppm	9.9	10.2	7.12	7.02	37	39
Zn 200 ppm	10.1	10.3	6.88	6.69	40	41
B 100 ppm	10.8	11.0	6.77	6.65	41	42
B 200 ppm	11.3	11.2	6.61	6.49	42	45
Fe + Zn + B (at 100ppm)	11.9	12.1	6.12	6.11	43	47
Fe + Zn + B (at 200ppm)	12.4	12.6	6.09	6.02	48	48
Mean	**10.6**	**10.8**	**6.81**	**6.71**	**38**	**39**
New LSD at 5%	**1.1**	**0.9**	**0.08**	**0.07**	**8**	**12**

The improvement in fruit chemical properties is associated with enhanced photosynthesis, nutrient assimilation and antioxidant metabolism due to the combined foliar application of the three micronutrients. Fe, Zn and B contribute to vitamin C biosynthesis and acid regulation, resulting in higher TSS, lower acidity and increased vitamin C content. These findings are consistent with previous studies showing that foliar the micronutrients improve fruit quality in citrus crops. Zinc is essential for the function of carbonic anhydrase enzyme that participates in photosynthesis and carbon fixation. Zinc deficiency reduces photosynthesis and results in decreased TSS. **Broadley *et al.* (2007)** clarified that zinc participates in carbohydrate metabolism and conversion of starch to simple sugars. The notable increase in vitamin C (ascorbic acid) content has great nutritional importance. Vitamin C is a powerful antioxidant and essential for human health. Iron and zinc play a role in vitamin C synthesis through their effect on enzymes involved in the biosynthesis pathway. **Davey *et al.* (2000)** proved in their study that micronutrient availability, especially iron and zinc, enhances ascorbic acid synthesis in plant tissues. Boron contributes to enhancing vitamin C content through its effect on sugar transport, which are considered the basic precursor for ascorbic acid synthesis. **Wojcik and Wojcik (2006)** found that boron spraying on apple trees increased vitamin C content in fruits by 15-20%. The decrease in total acidity with combined treatments is attributed to improved respiration and consumption of organic acids. The optimal balance between sugars and acids determines taste and flavor. **Etxeberria and Narciso (2015)** indicated that TSS/acidity ratio is considered the best indicator for evaluating citrus taste quality. The improvement in fruit chemical quality reflects the synergistic effect of combined treatments on secondary metabolism. **Alos *et al.* (2006)** confirmed in their study that optimal nutritional balance enhances accumulation of secondary compounds responsible for fruit quality, including mineral and vitamins.

5. Conclusion

In order to improvement of Balady lime production and fruit physicochemical properties quality, under new reclamation desert land in Minia Governorate, it recommended to spraying the Fe, Zn and B at 200 ppm three times yearly, first one at Early February, the second at Early April and last one at Early May.

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