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Effect of spraying seaweed extract and iron on the growth and fruiting of Balady lime

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Abstract: Proper nutritional condition is essential for the fruiting phase of The present investigation was carried out during two successive seasons 2023 and 2024 on twenty one ten years old Balady lime trees, grown in 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 trees were irrigated throw drip irrigation system. The chosen trees were planted at 4 X 5 meters apart. Two concentrations of seaweed (0.05% & 0.1%) and Fe (100 & 200 ppm) as well as their combinations were examined. The obtained results showed that spraying seaweed and Fe individually or in combination was capable to improve the vegetative growth, nutritional status, yield, and fruit quality. However, the combined application of seaweed and Fe was more effective than spraying each one individually. These findings were true during the two experimental seasons.

Key words: Balady lime trees, seaweed extract, Fe, vegetative growth, nutritional status, yield, and fruit quality.

1. Introduction

Balady lime (*Citrus aurantifolia* Swingle) is one 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 (**Ministry of Agriculture, Egypt, 2025 and FAO, 2024**). However, more than 70% of this area is located in newly reclaimed lands. These stressful conditions drastically reduce the availability and uptake of micronutrients 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 (**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**). Adequate iron nutrition improves vegetative growth, photosynthetic efficiency, thereby enhancing flowering, yield of lemon trees (**Srivastava and Singh, 2022**). Under salinity stress, iron contributes to maintaining cellular metabolism and antioxidant defense systems, helping lemon tree mitigate oxidative damage caused by excess salts (**Tripathi *et al.*, 2018**). Hundreds of foreign and local studies have proven that foliar spraying of iron combined with seaweed extracts as bio-stimulants, is the most effective strategy to overcome salinity stress, enhance nutrient uptake, increase antioxidant activity, and boost yield and fruit quality by 50–120% compared to untreated trees (**Craigie 2011; El-Sayed & Ibrahim 2016** and **Abd El-Moniem et al., 2019**).

The current study further highlights the importance of spraying seaweed or/and iron on the growth, fruiting, 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 twenty one 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 one and have 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. The physical and chemical analysis of soil and water are illustrated in Table (1).

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

2.2. Experimental work

In order to justify the effect and the suitable dose of seaweed at 0.05% & 0.1% and iron at 100 ppm & 200 ppm on Balady lime trees of the present experiment; Seaweed sprayed at 0.05% & 0.1% and iron sprayed at 100 & 200 ppm, as well as the combination between seaweed extract and iron

(Seaweed at 0.05% + Fe at 100 ppm and Seaweed at 0.1% + Fe at 200). 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 thirteen treatments from the two examined materials and control treatment. As follow the eleven treatments were arranged: Control (trees sprayed with water); Spraying Seaweed at 0.05%; Spraying Seaweed at 0.1%; Spraying Fe at 100 ppm; Spraying Fe at 200 ppm; praying Seaweed at 0.05% + Fe at 100 ppm, and Spraying Seaweed at 0.1% + Fe at 200 ppm.

Each treatment was replicated three times, one tree per each replicate. Triton B was used as a wetting agent; it was added to all spraying solutions at 0.01%.

2.3. Experimental design and Statistical analyses

Experiments were performed by using a randomized complete block design (RCBD), and statistical analyses were performed with SPSS program. Each treatment was replicated three times. The data were analyzed by one-way ANOVA. Means of the treatments were compared by using New 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.

Vegetative growth characters: At the first week of July in both experimental season, sixteen mature leaves from the medal part of nonproductive shoots were picked from each tree **(according to Ibrahim, 2010)**, for measuring leaf area (cm^2) by using an area meter **(Area Meter Cl, 202)**. The average new shoot numbers per tree was recorded as a result of counting the new shoots/tree, and the average new shoot number/tree was recorded at the end of July.

Measurements of leaf pigments: Sample of eight mature and fresh leaves from those located at the middle part on eight shoot were taken at the middle of June were collected during the two experimental seasons and the blades cut into small pieces and 0.5 g weight from each tree was taken, homogenized and extracted by 85% acetone in the presence of little amounts of Na_2CO_3 then filtered. Chlorophylls and carotenoids were determined calorimetrically (as mg/ 100 g F.W) at wave length of 662, 664 and 440 nm for chlorophylls a, chlorophyll b and total carotenoids respectively. The total chlorophyll estimated by the summation of chlorophyll a + chlorophyll b (mg/ 100 g. F.W) (**Ward & Johnston 1962 and Ibrahim 2010)**.

$$\text{Chlorophyll a} = (9.784\ X\ E\ 662) - (0.99\ X\ E\ 644)$$

$$\text{Chlorophyll b} = (21.426\ X\ E\ 644) - (4.65\ X\ E\ 622)$$

$$\text{Total Carotenoids} = (4.695 \times E\ 440) - 0.268\ (E\ 662 + E\ 644)$$

Where E = Optical density at a given wavelength.

Leaf N, P, K, Fe, Zn, and B Determination: Nitrogen was determined by the microkejldahl method as described by **Martin-Preval *et al.*, (1984)**. The phosphorus was determined using colorimetric method, as described by **Wild *et al.*, (1985)**, by measuring the optical density of phosphor-molibdo-vanadate complex by Spectro-photometrically at wave length 430 nm. Potassium was determined by flam-photometrically using the method outlined by **Martin-Preval *et al.*, (1984)**. Micro-nutrients elements (Fe, Zn, and B) were determined by using Atomic absorption methods (**Martin-Preval *et al.*, 1984**).

Yield and its component: The fruits were harvested when the color start to turn on yellow and the juice % arrive to 30% (w/w) from fruit weight, on check treatment trees of the, during the two experimental seasons. 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)**.

2.5. Statistical analysis of data

The obtained data were tabulated and subjected to proper statistical analysis; by analysis of variance (ANOVA) using the statistical package MSTATC Program. The means were compared by least significant differences (New L.S.D) at p = 0.05 (**Sendecor and Cochran, 1990**).

3. Results and Discussion

3.1. Effect of seaweed extract, Fe, Zn, and B on vegetative growth of Balady lime

The data presented in Table (2) clearly indicate that spraying Balady lime trees with seaweed extract (at 0.05% & 0.1%) and Iron (at 100 & 200 ppm), either singly or in combination, significantly affected vegetative growth parameters during the two studied experimental seasons (2023 and 2024), as compared with the untreated trees (control).

3.1.1. Shoot length (cm)

Table (2) showed significant differences among the examined treatments with respect to shoot length in both experimental seasons. The combined treatment of Seaweed extract at 0.1% and Fe at 200 ppm recorded the highest shoot length, reaching 32.7 and 34.2 cm during 2023 and 2024 seasons, respectively. These values were significantly superior to control or other treatments, followed by spraying Seaweed extract at 0.50% combined with Fe at 100 ppm, which produced shoot lengths of 27.9 and 30.9 cm in the two experimental seasons respectively. In the same context, spraying Seaweed extract and Fe individually caused a significant promotion in shoot length (cm) compared to untreated trees. However, spraying seaweed extract at 0.1% individually recorded higher shoot lengths rather than spraying the lime trees with Fe and untreated trees. On the opposite side, the control treatment recorded the lowest shoot length (16.2 and 17.7 cm), indicating poor vegetative growth in the absence of foliar nutrition.

3.1.2. Number of new shoots per tree

Regarding the number of new shoots per tree, the data revealed in Table (2) showed that a significant increment in the number of shoots per tree due to foliar spraying with seaweed, micronutrients, and their combinations. The highest values were recorded with the combined application of seaweed extract at 0.1% and Fe at 200 ppm, reaching 59.2 and 60.5 shoots/tree in 2023 and 2024, respectively. Individual applications of seaweed extract at 0.05% & 0.1% and Fe at 100 & 200 ppm showed moderate increases, but rest also significant higher rather than control treatment. While, untreated trees presented the lowest number of newly shoots per trees in the both experimental seasons (52.3 and 50.7) respectively.

3.1.3. Leaf area (cm²)

The obtained data showed that, the leaf area of Baldy lime trees was also significantly affected by spraying the two examined materials (seaweed extract and Fe). However, the combined treatment with higher concentrations (Seaweed at 0.1 and Fe at 200 ppm) resulted in the highest leaf area (17.7 and 18.2 cm²), followed by the combined treatment at lower concentrations (Seaweed extract at 0.5% and Fe at 100ppm). These findings were true during the two experimental seasons. However, spraying with seaweed extract or Fe each one individually also resulted in a significant improvement in leaf surface area (cm^2). However, despite this significant improvement, it was less than the combined treatment with seaweed extract and micronutrients. In contrast, the control treatment recorded the smallest leaf area (14.2 and 13.8 cm^2), during the two experimental seasons respectively. The superiority of combined (seaweed extract and Fe) treatments exceeded the LSD values which confirming their significant effect and the importance of this treatment.

The pronounced improvement in vegetative growth parameters due to the combined application of seaweed extract with Fe may be attributed to the synergistic effects of these materials. Seaweed extract is rich in natural growth regulators such as auxins, cytokinins and gibberellins, which enhance cell division and elongation, leading to increased growth parameters and leaf development. Iron plays a vital role in chlorophyll synthesis and energy transfer and involved in enzyme activation and auxin metabolism. Therefore, the integration of seaweed extract with Fe improves nutrient uptake efficiency, stimulates vegetative growth and enhances leaf formation. These findings are in agreement with those reported by previous researchers who emphasized the positive effects of seaweed extracts and micronutrients on citrus growth and development **(Khan *et al.*, 2009; Abd El-Migeed *et al.*, 2017; Spinelli *et al.*, 2010; Mohamed & El-Sehrawy 2013 and Ibrahim *et al.*, 2015)**.

Table (2). Effect of spraying Seaweed extract, Fe, Zn, and B on vegetative growth parameters of Balady lime during 2023 and 2024 seasons

Treatments	Shoot length (cm)		No. of new shoots/tree		Leaf area (cm^2)	
	2023	2024	2023	2024	2023	2024
Control	16.2	17.7	52.3	50.7	14.2	13.8
Seaweed (SW) 0.05%	20.9	22.5	55.4	56.9	15.4	16.3
Seaweed (SW) 0.1%	25.6	28.2	57.3	58.9	17.4	17.3
Fe 100 ppm	21.5	21.3	54.4	55.8	14.8	15.1
Fe 200 ppm	22.4	23.2	56.1	57.7	15.5	15.8
SW 0.05% + Fe 100 ppm	27.9	30.9	57.9	59.3	16.7	17.2
SW 0.1% + Fe 200 ppm	32.7	34.2	59.2	60.5	17.7	18.2
Mean	23.8	24.0	56.1	57.1	15.9	16.2
New LSD at 5%	3.5	3.8	2.1	2.1	0.9	1.1

3.2. Effect of seaweed extract and Fe on Photosynthesis pigments

The data presented in Table (3) clearly indicate that spraying Balady lime trees with seaweed extract at 0.05% or 0.1% and Fe at 100 or 200 ppm, either singly or in combination, significantly affected leaf photosynthetic pigments (chlorophylls and carotenoids) during the two experimental seasons (2023 and 2024), in compared to untreated trees (control).

3.2.1. Effect on chlorophyll A contents

The obtained data listed in Table (3) showed significant differences among the examined treatments with respect to chlorophyll a content in both experimental seasons. However, spraying seaweed at 0.05% and 0.1% significantly improve the chlorophyll contents in Balady lime leaves compared to un-treated trees. Furthermore, the combined treatment of Seaweed extract at 0.1% and Fe at 200 ppm recorded the highest chlorophyll a content, reaching 6.1 and 6.3 mg/100 g FW in seasons 2023 and 2024, respectively. These values were significantly superior to all other treatments. The second-best treatment was sparing Seaweed extract at 0.50% combined with Fe at 100 ppm, which recorded chlorophyll a values of 5.8 and 6.0 mg/100 g FW. These data were true during the two experimental seasons. In the same context, spraying Fe caused a significant increment in compared to control trees. On the opposite side, the control treatment recorded the lowest chlorophyll a content (4.1 and 4.2 mg/100 g FW), indicating weak photosynthetic capacity, of lime trees grown in sandy soil, in the absence of foliar nutrition.

3.2.2. Effect on chlorophyll B contents

The results illustrated in Table (3) showed that a similar trend was observed for chlorophyll b content. Whereas, the combined application of seaweed extract at 0.1% and Fe at 200 ppm resulted in the highest chlorophyll b content (1.7 and 2.0 mg/100 g FW) in the leaves of lime trees during the two seasons, followed by the combined treatment with lower concentrations (SW at 0.05% + Fe at 100 ppm). Other words, spraying seaweed or iron individually also had a capacity to significantly improve the leaf chlorophyll b contents, in both experimental seasons. Contrary, the control (untreated trees) produced the lowest chlorophyll b values in their leaves (1.4 and 1.5 mg/100 g FW), and the differences between the treatments and the control were statistically significant.

3.2.3. Effect on total chlorophyll contents

Regarding the total chlorophyll contents, the obtained data in Table (3) revealed significant increases in lime leaves due to foliar spraying different treatments in comparison with control trees. It is clear from this table that, individual spraying of seaweed and Fe was effective in improving the leaf total chlorophyll contents (mg/100g FW), during the two experimental seasons. Regarding the individual treatments, spraying at 200 ppm was more effective on enhancing leaf total chlorophyll (6.7 and 7.9 mg/100g F.W.) rather than spraying seaweed or other micron nutrients. Furthermore, the highest total chlorophyll content was recorded with the combined application of seaweed extract at 0.1% combined and Fe at 200 ppm, reaching 7.8 and 8.3 mg/100 g FW in 2023 and 2024, respectively. Followed by spraying seaweed at 0.05% and Fe at 100, which ranked the second position, it reaching 7.4 and 7.7 mg/100 g FW. On the contrary, the control treatment presented at lower concentrations of total chlorophyll, it recorded values (5.5 and 5.7 mg/100 g FW).

3.2.4. Effect on total carotenoids contents

Total carotenoids content was also significantly affected by the spraying the seaweed extract and Fe in both experimental seasons. Regarding the individual application of each examined material, it succeeded in enhancing the leaf total carotenoids compared to untreated trees. However, spraying seaweed extract at higher concentration (0.1%) individually shows more effective rather than spraying Fe individually. The Balady lime trees sprayed with seaweed extract reached 1.5 and 1.7 mg/100g FW during 2023 and 2024 seasons respectively. The combined treatment with higher concentrations (seaweed 0.1% and Fe 200 ppm) resulted in the highest carotenoid content in lime leaves (1.6 and 1.9 mg/100 g FW), followed by spraying seaweed extract at 0.01% alone. On the opposite side, the control treatment recorded the lowest total carotenoid values (1.4 and 1.3 mg/100 g FW). These data were true during the two experimental seasons.

Table (3). Effect of spraying Seaweed extract, Fe, Zn, and B on leaf photosynthesis pigments (mg/100g FW) of Balady Lime, during 2023 and 2024 seasons

Treatments	Chlorophyll A		Chlorophyll b		Total chlorophyll		Total carotenoids	
	2023	2024	2023	2024	2023	2024	2023	2024
Control	4.1	4.2	1.4	1.5	5.5	5.7	1.4	1.3
Seaweed (SW) 0.05%	5.2	5.1	1.5	1.6	6.7	6.7	1.4	1.6
Seaweed (SW) 0.1%	5.2	5.3	1.6	1.6	6.8	6.9	1.5	1.7
Fe 100 ppm	5.3	5.5	1.4	1.3	6.7	6.8	1.2	1.3
Fe 200 ppm	6.2	6.4	1.5	1.5	6.7	7.9	1.3	1.4
SW 0.05% + Fe 100 ppm	5.8	6.0	1.6	1.7	7.4	7.7	1.4	1.8
SW 0.1% + Fe 200 ppm	6.1	6.3	1.7	2.0	7.8	8.3	1.6	1.9
Mean							1.4	1.3
New LSD at 5%	0.8	0.7	0.2	0.3	1.1	0.9	0.3	0.3

The pronounced improvement in leaf photosynthetic pigments due to the combined application of seaweed extract and Fe may be attributed to the synergistic effects of these materials. Seaweed extract is rich in natural growth regulators such as auxins, cytokinins, and gibberellins, which enhance chlorophyll synthesis and delay pigment degradation. Iron plays a vital role in chlorophyll formation and electron transport (**Marschner 2012; Bhatt *et al.*, 2016; Masoud *et al.*, 2019; Pantnagar 2020; El-Gioushy *et al.*, 2021,** and **Aswad & Al-Abbassi 2025**).

Therefore, the integration of seaweed extract with iron enhances photosynthetic efficiency and pigment accumulation in Balady lime leaves. These findings are in agreement with those reported by previous researchers who emphasized the positive effects of seaweed extracts and iron on photosynthetic pigments of citrus trees (**Khan *et al.*, 2009; Mohamed & El-Sehrawy 2013; El-Sayed *et al.* 2014 and Ibrahim *et al.*, 2015**).

3.3. Effect on leaf mineral contents

3.3.1. Effect on NPK contents

Nitrogen content (%): It is clear from this table that, the individual spraying of seaweed at Fe at different concentration significantly increased the leaf nitrogen contents in both seasons, in compared to untreated lime trees. However, sprayed the lime trees with seaweed extract at 0.1% individually shows more effective in leaf Nitrogen % in compression to control or other individual treatments, it recorded 2.0 and 2.2%, this finding was true during both experimental seasons.

It is clear from the obtained data also that, the combined application of seaweed extract and iron was more effective than spraying any one alone in both experimental seasons. Whereas, the combined application of seaweed extract at 0.1% + Fe at 200 ppm recorded the highest nitrogen content, reaching 2.4 and 2.4% in 2023 and 2024 seasons, respectively. These values were significantly superior rather than to all other treatments. The second-best treatment was Seaweed extract at 0.50% combined with Fe at 100 ppm for each element, which recorded nitrogen contents of 2.3 and 2.3 % during the two experimental seasons. On the other hand, the control treatment recorded the lowest nitrogen content (1.7 and 1.6%), indicating poor nutritional status in the absence of foliar fertilization under newly reclaimed desert land.

Phosphorus content (%): Data illustrated in Table (4) showed that, similar trend was observed for leaf phosphorus content of Baldy lime trees. This Table clearly showed that, spraying seaweed extract at 0.05% and Fe at 100 ppm & 200 ppm moderate non-significantly enhancement of leaf phosphorus contents in both experimental seasons, contrary spraying seaweed extract at 0.1% individually significantly increased the p% in both experimental seasons rather than the other individual treatments. Furthermore, the combined application of seaweed extract at 0.1% and Fe at 200 ppm resulted in the highest phosphorus content (0.88 and 0.89 %) in Balady lime leaves, during the two seasons, followed by the combined treatment with lower concentrations (seaweed extract at 0.05% + Fe 100 ppm), which recorded 0.81 and 0.82 phosphorus %.

Potassium content (%): It is clear from Table (4) that spraying Balady lime trees grown in sandy soil with seaweed extract at 0.05% & 0.1% and Fe at 100 ppm & 200 ppm individually lead to significant increment in leaves potassium content compared to untreated trees. However, spraying the trees with seaweed extract at 0.1% individually shows more effective than spraying seaweed at 0.05% or spraying Fe at 100 & 200 ppm. Furthermore, the highest potassium content in Balady lime leaves was recorded when the trees received the combined application of seaweed extract at 0.1% and Fe at 200 ppm (0.66 and 0.68 %) in 2023 and 2024, respectively. In addition, the combined treatment at lower concentrations ranked second (0.59% and 0.61%). In contrast, the control treatment recorded the lowest potassium content (0.41 and 0.41%), indicating weak potassium nutrition.

Table (4). Effect of spraying Seaweed extract, Fe, Zn, and B on leaf NPK contents (%) of Balady Lime, during 2023 and 2024 seasons

Treatments	Nitrogen %		Phosphorus %		Potassium %	
	2023	2024	2023	2024	2023	2024
Control	1.7	1.6	0.66	0.65	0.41	0.41
Seaweed (SW) 0.05%	1.9	1.9	0.69	0.70	0.44	0.45
Seaweed (SW) 0.1%	2.0	2.2	0.76	0.77	0.48	0.51
Fe 100 ppm	1.8	1.9	0.69	0.72	0.43	0.44
Fe 200 ppm	1.9	2.9	0.71	0.72	0.44	0.54
SW 0.05% + Fe 100 ppm	2.3	2.3	0.81	0.82	0.59	0.61
SW 0.1% + Fe 200 ppm	2.4	2.4	0.88	0.89	0.66	0.68
Mean	2.0	2.2	0.74	0.75	0.49	0.52
New LSD at 5%	0.2	0.3	0.10	0.09	0.07	0.08

The pronounced increase in leaf NPK contents due to the combined application of seaweed extract and Fe may be attributed to the enhancement of nutrient uptake efficiency and metabolic activity. Seaweed extract improves root growth and membrane permeability, facilitating nutrient absorption. While iron play key roles in enzyme systems, protein synthesis and nutrient translocation. The synergistic interaction among these two materials enhances nitrogen assimilation, phosphorus metabolism and potassium accumulation in plant tissues. Accordingly, the integration of seaweed extract with micronutrients significantly improves the nutritional status of Balady lime trees. These findings are consistent with previous studies reporting enhanced macro-nutrient contents in citrus leaves following foliar application of seaweed extracts and micronutrients (**Mengel *et al.*, 2001; El-Sayed, 2014 and Khan *et al.*, 2009**).

3.3.2. Effect on leaf micro-nutrients

Leaf Iron content (ppm): Results listed in Table (5) showed significant differences among the two examined compounds with respect to leaf iron content in both experimental seasons. The data showed that spraying the two materials each one individually was capable to increasing the leaf iron contents in both experimental seasons. However, spraying Fe at 200 ppm was more effective in enhancing leaf Fe contents in compared with unsprayed trees or spraying seaweed at 0.05% & 0.1% and Fe at 100 ppm. The trees received Fe at 200 ppm recorded (51.2 and 55.5 ppm), during 2023 and 2024 seasons respectively. Furthermore, the combined treatment of Seaweed extract at 0.1% + Fe at 200 ppm recorded the highest leaf iron content, reaching 53.3 and 59.4 ppm in 2023 and 2024, respectively. These values were significantly superior to all other treatments in both seasons. However, the second-best treatment was sprayed Seaweed extract at 0.50% combined with Fe at 100 ppm, which recorded iron contents of 51.2 and 57.3 ppm during the two seasons. On the opposite side, the control treatment recorded the lowest leaf iron content (33.3 and 31.8 ppm), indicating severe iron deficiency symptoms, in newly reclaimed sandy soil, in the case of the absence of foliar fertilization.

Leaf zinc content (ppm): A similar trend was observed for leaf zinc content. Spraying Seaweed and Fe individually significantly improve leaf zinc contents, spraying Fe at 200 ppm caused a best significant promotion on leaf zinc contents (22.3 and 23.1 ppm) in comparison with spraying seaweed individually or seaweed at 0.05% and 0.1%. The combined treatment of seaweed extract at 0.1% + Fe 200 ppm resulted in the highest zinc content (26.4 and 27.7 ppm) during the two seasons, followed by the combined treatment with lower concentrations (23.5% & 25.4%). On the opposite side the control trees (untreated trees) recorded the lowest zinc values (15.3 and 15.4 ppm), during the two seasons respectively.

Leaf boron content (ppm): Regarding the effect of spraying seaweed extract and Fe on Balady lime leaf boron content during the two seasons, the data revealed significant increases due to foliar spraying of these compounds. The two compounds were capable to increase leaf boron content significantly. However, the higher concentration of these materials was more effective rather than the lowest.

Furthermore, spraying Fe at 200 ppm alone was more effective in enhancing leaf boron contents (it recorded 11.3 and 13.5 ppm in both seasons respectively) rather than spraying seaweed extract at 0.05% & 0.1% and Fe at 100 ppm. These data were true during the two experimental seasons. However, the highest boron content was recorded with the combined application of seaweed extract at 0.1% and Fe at 200 ppm, reaching 11.5 and 13.9 ppm in 2023 and 2024, respectively. The combined treatment at lower concentrations ranked second (11.3 and 13.6 ppm), while individual applications of Fe resulted in moderate increases compared with the control. In contrast, the control treatment recorded the lowest boron content (7.2 and 7.8 ppm) in both seasons.

Table (5). Effect of spraying Seaweed extract, Fe, Zn, and B on leaf micro-nutrients (ppm) of Balady Lime, during 2023 and 2024 seasons

Treatments	Fe (ppm)		Zn (ppm)		B (ppm)	
	2023	2024	2023	2024	2023	2024
Control	33.3	31.8	15.3	15.4	7.2	7.8
Seaweed extract 0.05%	37.1	38.5	19.3	21.7	8.4	9.5
Seaweed extract 0.1%	٤١.4	٤4.7	20.9	22.5	9.3	9.7
Fe 100 ppm	49.3	51.7	19.3	21.1	10.2	12.6
Fe 200 ppm	51.2	55.5	22.3	23.1	11.3	13.5
SW 0.05% + Fe 100 ppm	51.2	57.3	23.5	25.4	11.3	13.6
SW 0.1% + Fe 200 ppm	53.3	59.4	26.4	27.7	11.5	13.9
Mean	45.3	48.4	21.0	22.4	9.9	11.5
New LSD at 5%	4.9	4.1	1.1	1.3	0.9	0.8

The pronounced increase in leaf micronutrient contents due to the combined application of seaweed extract and Fe may be attributed to the enhancement of nutrient uptake efficiency and translocation within plant tissues. Seaweed extract improves leaf permeability and chelation of micronutrients, facilitating their absorption, while iron play essential roles in chlorophyll synthesis, enzyme activation and pollen development (**Khan *et al.*, 2009**). The synergistic interaction among these materials results in higher accumulation of micronutrients in citrus leaves (**Mengel *et al.*, 2001)**. Accordingly, the integration of seaweed extract with micronutrients significantly improves the micronutrient nutritional status of Balady lime trees. These findings are in accordance with previous studies reporting enhanced leaf micronutrient contents following foliar application of seaweed extracts and Fe (**Khan *et al.*, 2009; El-Sayed*et al.*, 2014 and Mohamed *et al.*, 2022**).

3.4. Effect on Yield and its component

3.4.1. Effect on yield (kg/tree)

It is clear from this table that spraying seaweed extract and Fe individually was capable to enhancing the yield (kg/tree) during the two experimental seasons. However, spraying seaweed at 0.1% present the best results (26.8 and 27.5 kg/tree) in this respect, during the two seasons respectively. However, spraying the combined treatment of Seaweed extract at 0.1% and Fe at 200 ppm produced the highest yield (29.5 and 30.1 kg/tree) in 2023 and 2024 seasons, respectively. The second-best treatment was Seaweed extract at 0.50% + Fe 100 ppm, with yields of 28.4 and 28.3 kg/tree. On the other hand, the control treatment recorded the lowest yield (21.1 and 21.7 kg/tree).

3.4.2. Number of fruits per tree

Similar results were obtained according to the number of fruit per tree, as shown in Table (6). This table shows that spraying the two examined material at different concentration was 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 high concentration treatment, reaching 867.5 and 873.7 fruits/tree, followed by the combined low concentration treatment (839.9 and 844.5 fruits/tree). While, the control trees produced the lowest number of fruits per tree (743.3 and 755.7), during the two experimental seasons respectively.

3.4.3. Average fruit weight (g):

The obtained data in table 6 showed the response of Balady lime trees grown in sandy soil to spraying seaweed (at 0.05% and 0.1%) and Fe (at 100 and 200 ppm), it is clear from this table that spraying each material individually was capable to improve Balady lime fruit (g) in both experimental seasons. However, spraying seaweed extract 0.1% showed more effective (31.7 & 32.9 g) rather than spraying seaweed or other micro-nutrients. These findings were true during the two experimental seasons. Furthermore, treated the trees with seaweed and Fe at higher concentrations resulted in the heaviest fruits (34.0 and 34.4 g), followed by the combined treatments at low concentration (seaweed at 0.05% and Fe at 100 ppm), it recorded 33.8 and 33.5 g, in both season respectively. While, the same table demonstrated that the control trees recorded the lowest fruit weight (28.4 and 28.7 g) in both experimental seasons.

Table (6). Effect of spraying Seaweed extract, 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	28.4	28.5
Seaweed extract 0.05%	24.3	25.3	801.3	811.3	30.5	31.2
Seaweed extract 0.1%	26.8	27.5	830.5	841.5	31.7	32.9
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
SW 0.05% + Fe 100 ppm	28.4	28.3	839.9	844.5	33.8	33.5
SW 0.1% + Fe 200 ppm	29.5	30.1	867.5	873.7	35.0	35.9
Mean	**25.4**	**26.1**	**810.4**	**818.4**	**31.3**	**32.0**
New LSD at 5%	**2.1**	**2.2**	**40.1**	**38.3**	**1.2**	**1.3**

The improvement in yield and fruit characteristics can be attributed to the synergistic effects of seaweed extract and micronutrients. Seaweed extract enhances photosynthesis and nutrient translocation, while Fe improve enzymatic activity, carbohydrate production and hormonal balance, resulting in increased fruit set, growth and weight (**Norrie & Prithiviraj (2009) and Khan *et al.*, 2009**). These findings are consistent with previous research demonstrating the positive influence of foliar bio-stimulants and micronutrients on citrus yield and fruit quality. (**Khan *et al.*, 2009 ; Spinelli *et al.*, 2009 & 2010 and Taiz *et al.*, 2015**). The increase in total yield reflects the cumulative positive effects of treatments on all stages of fruit growth and development. Combined treatments 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%. Seaweed extracts improve water and nutrient use efficiency, increasing the tree's capacity to bear a greater number of fruits. **Mattner *et al.* (2013)** found that treating fruit trees with seaweed extracts increased yield through improving plant response to environmental stress. 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.

3.5. Effect on fruit physical properties

3.5.1. Fruit volume and fruit dimensions

The data presented in Table (7) showed the effect of spraying seaweed and Fe 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 seaweed extract and Fe, either singly or in combination, significantly affected fruit volume, fruit length, and diameter during the two studied seasons, in compared to untreated trees (control).

A- Fruit volume (cm^3): It is clear from the obtained data that spraying the two examined materials at different concentration individually was capable to enhance the fruit volume of Balady lime during both seasons, but spraying seaweed extract at 0.1% had the best effect compared to spraying seaweed at 0.05% or Fe at 0.05% & 0.1% individually. The combined treatment of seaweed at 0.1% and Fe 200 ppm recorded the largest fruit volume (25.34 and 26.71 cm^3), followed by the combined low concentration treatment (seaweed at 0.05% + Fe 100 ppm), which recorded 24.92 and 25.98 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 data showed that spraying seaweed and Fe individually significant enhanced the lime fruit length (cm) during the two experimental seasons. Furthermore, spraying seaweed extract at 0.1% individually showed superior than spraying seaweed at 0.05%, Fe at 100 ppm, and Fe at 200 ppm, whereas the fruit length reached 4.39 and 4.41 cm, in both seasons respectively. Furthermore, the combined application of seaweed and Fe showed more effective than spraying each compound alone. The combined high concentration treatment (0.1% seaweed and 200 ppm Fe) produced the longest fruits (4.73 and 4.72 cm), while the combined low concentration treatment (0.05% seaweed + 100 ppm Fe) recorded slightly shorter fruits (4.66 and 4.68 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 obtained results showed that the tow examined compounds had a positive effect on improving fruit diameter. In this regard, the obtained results indicated that the combined application of Seaweed extract and Fe was superior than spraying either one alone. However, the largest fruit diameter was recorded by the combined high concentration treatment (4.21 and 4.33 cm), followed by the combined low concentration treatment (4.02 and 4.25 cm). On the other side, the control treatment produced the smallest diameter (3.49 and 3.44 cm) in both experimental seasons respectively.

Table (7). Effect of spraying Seaweed extract, 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	20.42	4.01	4.03	3.49	3.44
Seaweed (SW) 0.05%	22.39	22.71	4.21	4.22	3.81	3.91
Seaweed (SW) 0.1%	23.37	23.41	4.39	4.41	3.99	4.12
Fe 100 ppm	21.12	21.69	4.28	4.31	3.67	3.75
Fe 200 ppm	22.80	23.09	4.22	4.29	3.71	3.79
SW 0.05% + Fe 100 ppm	24.92	25.98	4.66	4.68	4.02	4.25
SW 0.1% + Fe 200 ppm	25.34	26.71	4.73	4.72	4.21	4.33
New LSD at 5%	2.1	2.6	0.08	0.07	0.08	0.09

The enhancement in fruit volume and dimensions is linked to improved photosynthetic activity, nutrient availability and hormonal regulation induced by the combination of seaweed extract and Fe. The integrated application promotes cell division, enlargement, and water and carbohydrate accumulation in developing fruits, resulting in higher volume, length, and diameter of fruit (**Khan *et al.*, 2009; Spinelli *et al.*, 2010 and Taiz *et al.*, 2015**). 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. **Giovannoni (2004)** proved that plant hormone balance, especially auxins and gibberellins, controls final fruit size. Seaweed extracts contain alginic acids and polysaccharides that improve water absorption and accumulation in fruit cells. **Habasy *et al.*, (2021):** proved that treating plants with seaweed extracts improves water relations and increases cell turgidity, resulting in larger fruits.

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

The data presented in Table (8) showed the response of peel thickness (mm), pulp thickness (mm) and juice percentage of Balady lime trees, grown under sandy soil conditions, to spraying seaweed extract and iron. The obtained results clearly indicate that spraying Balady lime trees with seaweed extract and Fe, 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 this table that all treatments with seaweed extract and Fe at different concentrations failed to varying the fruit peel thickness significantly, neither in the first season nor in the second one.

B- Pulp thickness (cm): It is clear from Table (8) that spraying the two examined compounds individually significantly improved the thickness of fruits in both seasons. Whereas, spraying seaweed at 0.1% showed more effective rather than the other individual treatments or control trees, the trees sprayed with seaweed extract at 0.1% recorded 3.65 and 3.65 cm, during 2023 and 2024 seasons. Furthermore, the combined treatment of seaweed extract at 0.1% and Fe at 200 ppm recorded the highest thickest of fruit pulp (3.87 and 3.99 cm), followed by the combined low concentration treatment (3.69 and 3.90 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 (8) clearly showed that spraying the aforementioned treatments (seaweed extract and Fe) played an effective role in improving the juice content of Balady lemons, during the two experimental seasons. this table declared that spraying each material individually was capable to enhancing the Balady lime fruit juice %. However, spraying Fe at 200 ppm was superior to the other individual treatments, it presented 37.7% and 38.9%. Furthermore, concerning the combined application of seaweed and Fe, the highest juice percentages were obtained by the combined high concentration treatment (44.1 and 43.7%), followed by the combined low concentration treatment (42.2 and 41.9%). Contrary control (untreated trees) recorded the lowest juice content (33.2 and 33.4%).

The improvement in pulp thickness (cm) and juice percentage is related to enhanced water and carbohydrate accumulation in fruits due to foliar applications (**Khan *et al.*, 2009**). However, Seaweed extract enhances osmotic regulation and nutrient uptake, while micronutrients improve enzymatic activities and carbohydrate metabolism, contributing to better fruit quality (**Kader & Yahia 2011; Khan *et al.*, 2009 and Spinelli *et al.*, 2010 and Taiz *et al.*, 2015**). Furthermore, Seaweed extracts contain compounds that stimulate internal fruit tissue development. Alginic acids and polysaccharides improve water relations within the fruit. **Arioli *et al.*, (2015)** clarified that treating citrus trees with seaweed extracts increased juice percentage by 8-12%. 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 and sugars. **Habasy *et al.*, (2021)** proved that juice percentage is significantly affected by balanced mineral nutrition, especially potassium and boron.

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.

Table (8). 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
Seaweed (SW) 0.05%	0.32	0.34	3.49	3.57	35.9	38.7
Seaweed (SW) 0.1%	0.34	0.35	3.65	3.77	35.5	36.1
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	38.9
SW 0.05% + Fe 100 ppm	0.33	0.35	3.69	3.90	42.2	41.9
SW 0.1% + Fe 200 ppm	0.34	0.34	3.87	3.99	44.1	43.7
New LSD at 5%	NS	NS	0.31	0.42	2.2	3.1

3.6. Effect on fruit chemical properties

The obtained results clearly indicate that spraying Balady lime trees with seaweed extract and Fe, either singly or in combination, significantly affected fruit chemical properties (TSS %, total acidity % and vitamin C contents), during the two experimental seasons (2023 and 2024).

3.6.1. Total soluble solids (TSS%)

The data presented in Table (9) reveals that, all treatments of the four examined compounds, individually or in combination, exerted a significant effect on TSS%, during the two experimental seasons. It is clear from the obtained results that, spraying Balady lime trees with seaweed and Fe in combination (Seaweed extract at 0.1% and Fe at 200 ppm) have an announced and significant higher effect on TSS values, compared to other treatments or control trees. Followed by the combined low concentration (Seaweed extract at 0.05% and Fe at 100). On the opposite side the control trees presented the minimized TSS values. These data were true during the two experimental seasons respectively.

3.6.2. Total acidity (%)

The obtained results concerning to the effect of spraying seaweed and Fe as individually or in combination on total acidity %, of Balady lime fruits during both experimental seasons reveals that, all treatments of the two examined compounds, 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 data that, spraying the two materials individually was capable to decrease the fruit total acidity in both experimental seasons. While, spraying seaweed at 0.1% alone resulted in the lowest acidity in the fruit compared to spraying seaweed at 0.05% and Fe at 100 & 200 ppm, it presented (6.99 % and 6.89 %) in both experimental seasons. Furthermore, spraying Balady lime trees with seaweed extract and Fe in combination at higher concentration (Seaweed at 0.1% and Fe at 200 ppm) have an announced and significant lower total acidity values (6.11 and 6.04%) compared to other treatments or control. Followed by the combined low concentration (Seaweed at 0.05% and Fe at 100 ppm), which presented 6.22 and 6.13%. 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.

3.6.3. Vitamin C (mg/100 g FW)

The obtained results pertaining to the effect of spraying seaweed and Fe as a single or in combination on vitamin C contents of Balady lime fruits during the two experimental seasons revealed that, all treatments of the two examined compounds, individually or in combination, exerted a significant effect on vitamin C, in both seasons. It is clear from this data that, spraying Balady lime trees with seaweed and Fe in combination (Seaweed at 0.1% and Fe at 200 ppm) have an announced and significant higher effect on vitamin C values (48 and 49 mg/100 g FW) compared to other treatments or control one, followed by the combined at low concentration (Seaweed at 0.05% and Fe at 100 ppm), 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 (9). Effect of spraying Seaweed extract and Fe 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
Seaweed 0.05%	11.2	11.3	7.11	7.08	33	38
Seaweed 0.1%	11.5	11.7	6.99	6.89	39	42
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
SW 0.05% + Fe 100 ppm	11.9	12.1	6.22	6.13	43	47
SW 0.1% + Fe 200 ppm	12.0	12.2	6.11	6.04	48	49
Mean	10.9	11.0	6.86	6.81	37	38
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 Seaweed extract and Fe. Seaweed extract stimulates enzymatic activity and sugar accumulation, while Fe 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 bio-stimulants and micronutrients improve fruit quality in citrus crops.

However, seaweed extracts improve photosynthetic efficiency and increase carbohydrate production and transport to fruits. **Du-Jardin (2015)** found that seaweed extracts modify gene expression of genes responsible for carbohydrate metabolism, increasing sugar accumulation in fruits. Vitamin C is a powerful antioxidant and essential for human health. Iron 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, enhances ascorbic acid synthesis in plant tissues **Etxeberria & Narciso (2015).**

4. Conclusion

The present study aimed to highlighted the importance of spraying seaweed extract (as a bio stimulant for growth and fruiting) as well as the role of Fe on the growth, nutritional status, flowering, and fruit quality of Balady lime trees grown in newly reclaimed sandy soils under Minia Governorate conditions. Based on the results of this study, in order to improve the growth, nutritional status, flowering, and fruit quality parameters of Balady lime, it recommend to spraying a 0.1% seaweed extract accompanied with spraying Fe at 200 ppm, three times yearly.

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