

Using Spirulina Extract as a Natural Bio stimulant to Improve Yield and Fruit Quality of Valencia Orange Trees

Nourhan A. F. Mashhour, Ahmed S. A. Hassan, Mohamed M. Ibrahim* and Doaa S. Mahmoud

Horticulture Department, Faculty of Agriculture, Zagazig University, Egypt

Corresponding author: Mohamed M. Ibrahim

E-mail: mmnasr79@zu.edu.eg

Abstract

This experimental was carried out on Valencia orange trees grown in private orchard located at Belbis district, Zagazig governorate, Egept during two consecutive seasons of 2022 and 2023. The trees were planted 5 x 5 meters apart. The texture of soil is calcareous sandy soil. The present study aimed to improve the yield and fruit quality of Valencia orange trees through foliar application of Spirulina algae extract at 1, 2, 3 and 4 cm/ L water. Trees were sprayed three times starting at the first week of March, May and July. The results showed that 4 ml/L proved to be the most effective concentration for achieving maximum improvements in most studied parameters, while 3 ml/L often produced statistically similar results and may therefore represent a more economical alternative under practical field conditions. Overall, Spirulina platensis can be recommended as a sustainable agricultural practice for enhancing citrus production and fruit quality due to its rich content of nutrients, amino acids, antioxidants, vitamins, and natural growth-promoting substances.

Keywords: Valencia orange, Spirulina algae, Yield, Fruit quality.

1. Introduction

Citrus is considered one of the most important fruit crops in Egypt due to its significant economic, nutritional, and export value. The crop plays a vital role in supporting the agricultural sector by generating income, creating employment opportunities, and contributing substantially to agricultural exports. Favorable climatic conditions and the continuous expansion of newly reclaimed lands have enabled Egypt to become one of the world's leading producers and exporters of citrus fruits, particularly sweet orange. The total citrus cultivated area is estimated at approximately 550,000 feddans, with an annual production exceeding 5 million tons. In addition, citrus represents the leading agricultural export commodity in Egypt, with exports surpassing 2.2 million tons (**Statistics of the Ministry of Agric., 2024**), reflecting its strategic importance in enhancing agricultural competitiveness and increasing foreign exchange earnings. Therefore, research efforts aimed at improving citrus productivity, fruit quality, and resource-use efficiency are of considerable importance for sustaining citrus production and maximizing its economic contribution to the Egyptian agricultural sector.

Spirulina platensis is a type of photosynthetic blue-green microalgae renowned for its nutritional benefits. This microalga is not only a valuable source of proteins, vitamins, essential amino acids, and fatty acids, but it has also been shown to promote plant growth by enhancing shoot length, leaf count per shoot, and leaf area, ultimately improving fruit quality. Its significance largely stems from its commercial potential (**Ciferri and Tibani, 1985; Vonshak and Richmond, 1985; Vonshak, 1986; Barron et al., 2008**).

Algae can be categorized into three pigment-based classes: green, brown, and red. Incorporating algae in various forms into plant care leads to positive impacts on growth and productivity (**Spinelli et al., 2009; Abdel-Mawgoud et al., 2010**). Spirulina platensis, in particular, is often regarded as a fundamental bio-fertilizer given its widespread importance as a source of proteins, vitamin B-12, amino acids, and antioxidants (**Henrikson,**

2010). Its ability to enhance plant development and crop yields can be attributed to its release of various growth-regulating substances, including gibberellin, auxin, and cytokinins (**Hashtroudi et al., 2013**).

Foliar application of algal extract has been suggested to enhance the development and production of many plants (**Awad et al., 2006; Nour et al., 2010; Pramanick et al., 2013; Shalaby and El-Ramady, 2014**). Enriched organic fertilizers with biofertilizers, mainly *Spirulina platensis* algae, were beneficial in improving yield quantitatively and qualitatively rather than applying organic fertilizers alone (**Ahmed et al., 2011**). Using *Spirulina platensis* algae in various fruit crops has a commensurable effect on vegetative growth, tree nutritional status, yield and fruit characteristics (**Aly-Samar, 2015**) on Flame seedless grapevines and (**Hussien, 2017**) on Swey date palm.

2. Objectives

This study was conducted to evaluate the effectiveness of foliar application of *Spirulina* algae extract in enhancing vegetative growth, yield performance, fruit quality attributes, and leaf chemical composition of Valencia orange (*Citrus sinensis* L. Osbeck) trees.

3. Materials and methods

This study was conducted in orchards located at Belbis district Zagazig governorate during two consecutive seasons of 2022 and 2023 in 15 Valencia orange trees were selected for achieving this study. The trees were planted 5 x 5 meters apart. The texture of soil is calcareous sandy soil. This study was conducted to assess the different effects of using *Spirulina platensis* algae on yield, physical and chemical characters of the Valencia orange fruit.

The selected trees were at the same age and uniform in vigor. These trees were 10 years old at the start of study, good physical conditions and free of insects, damage and diseases. The selected trees were irrigated through drip irrigation system.

Each selected tree received the common horticultural practices that are already applied in the orchard except those dealing with using *Spirulina platensis* algae. The treatments arranged as follows:

1. Control (sprayed trees with water).
2. Application of *Spirulina platensis* algae at (1 cm / 1 water).
3. Application of *Spirulina platensis* algae at (2 cm / 1 water).
4. Application of *Spirulina platensis* algae at (3 cm / 1 water).
5. Application of *Spirulina platensis* algae at (4 cm / 1 water).

This experiment was arranged in a randomized complete block design (RCBD). Each treatment replicated three times, one orange tree per replicate. Trees were sprayed three times starting at the first week of March and the other two sprays were conducted at two months intervals (1st week of May and July). Triton B as a wetting agent was added to *Spirulina platensis* algae solutions at 0.5 % and spraying was done till runoff (5L/tree). The Chemical analysis of *Spirulina platensis* are shown in Table (A) according to (**Barron et al., 2008**).

Tables A. The Chemical analysis of *Spirulina platensis*

Parameters	Values
General composition (per 100 g)	
Moisture	3.5 g.
Protein	63.5 g.
Fat (Lipids)	9.5 g.
Fibre	3.00 g.
Ash	6.70 g.
N- free extract	15. g.
Pigments	

Phycocyanin	15.6 g.
Carotenoids	456.00 mg.
Chlorophyll- a	1.30 g
Vitamins	
Provitamin A	213.00 mg.
Thiamin (V.B ₁)	1.92 mg.
Riboflavin (V. B ₂)	3.44 mg.
Vitamin B6	0.49 mg.
Vitamin B12	0.12 mg
Vitamin E	10.40 mg.
Niacin	11.30 mg.
Folic acid	40 mg.
Panthenic acid.	0.94 mg
Inositol	76.00 mg.
Minerals	
phosphorus.	916.00 mg
Iron	53.60 mg.
Calcium	168 mg.
Potassium	1.83 g.
Sodium	1.09 g.
Magnesium	250 mg.

The responses of the tested trees to the applied foliar treatments were evaluated through the following characteristics:

1. Fruit set and fruit retention percentages: The emerging flowers on four similar branches at the different tree directions were counted at the balloon stage by the end of March in each season. After fruit set, by the end of April, the setted fruitlets will be counted at the same branches. Fruit set percentage was calculated. The remaining fruits on the previously labeled branches will be counted before harvesting in the two seasons; fruit retention percentage will be then calculated.

2. Tree yield: At the commercial harvesting date of each season, the remaining fruits on each tree will be picked out and weighed. The average yield per tree (kg/tree) and the average number of fruits / trees were registered.

3. Fruiting efficiency was calculated by dividing fruit yield kg/tree on canopy volume (m³).

4. Fruit characteristics:

After fruit harvest, 15 fruits will be randomly collected from each replicate to determine the following fruit physio-chemical characteristics:

- Average fruit weight (g) and volume (cm³).
- Fruit dimensions [height (H) and diameter (D) (cm)] and fruit shape index (H/D).
- Average pulp and peel weights (g).
- Peel thickness (mm).
- Fruit firmness (kg/ inch²) by pressure tester.
- Average juice volume/ fruit (cm³).
- Titratable acidity percentage in fruit juice will be determined as citric acid by titration against 0.1 N sodium hydroxide solution in presence of phenolphthalein index as indicator and the total acidity percentage will be calculated (A.O.A.C., 2006).
- Total soluble solids percentage (TSS%) will be determined in fruit juice using a hand refractometer. TSS / acid ratio will be then calculated.
- Vitamin C content as mg / 100 ml juice will be determined by titration against 2, 6-dichlorophenol indophenol dye (A.O.A.C., 2006).
- Total, reducing and non-reducing sugars percentages will be determined in fruit juice according to Lane and Eynon (1965).

- Total Carbohydrates %.

The obtained data was subjected to analysis of variances (ANOVA) according to **Snedecor and Cochran (1980)**. The individual comparisons between the values obtained were carried out using LSD at 5% level.

4. Results and Discussion

Effect of spraying with *Spirulina platensis* extract on fruit set and retention percentages

Data in Table 1 reveals a critical physiological impact of *Spirulina platensis* extract on the reproductive success of Valencia orange trees. The treatment effectively addresses two major challenges in citrus production: low initial fruit set percentage.

There is a significant increase in the initial fruit set across all concentrations. The 4 ml/L treatment achieved the highest set percentage (41.83% in S1 and 44.56% in S2), nearly doubling the performance of the control group (24.58% and 21.75%). Scientifically, algal extracts are rich in natural growth regulators like cytokinin's and auxins, which promote pollen germination and tube growth, leading to higher successful fertilization rates and initial fruit development.

The statistical evidence strongly supports the use of *Spirulina platensis* extract at 4 ml/L to maximize both fruit set and retention. Scientifically, this translates to a higher final yield per tree, making it a valuable organic tool for citrus growers to ensure a more productive harvest.

Moreover, data in Table 1 clearly demonstrate that foliar application of *Spirulina platensis* extract significantly enhanced the reproductive performance of Valencia orange trees, as evidenced by the marked increases in fruit set and fruit retention percentages during both growing seasons. The superior performance of the 4 ml/L treatment suggests that *Spirulina platensis* acts as an effective natural bio stimulant capable of improving flowering efficiency, fertilization success, and fruit persistence under field conditions.

The positive effect of *Spirulina* extract on fruit set and retention may be attributed to its rich composition of essential nutrients, amino acids, vitamins, antioxidants, proteins, and naturally occurring phytohormones such as auxins, cytokinin's, and gibberellin-like substances. These bioactive compounds likely stimulate pollen viability, ovule fertilization, cell division, and early fruit development, thereby reducing physiological fruit drop and enhancing fruit retention. Moreover, *Spirulina*-induced improvement in leaf nutritional status and photosynthetic activity may increase carbohydrate availability to developing fruits, which is considered a key factor controlling fruit set stability and fruit retention in citrus species.

The obtained findings are consistent with those reported by **Salama (2015)** reported that algae extract application improved fruiting behavior and productivity of Valencia orange trees through enhancement of nutrient uptake and hormonal balance within the trees. In addition, **Kumar et al. (2022)** demonstrated that *Spirulina platensis* is a rich natural source of phytonutrients and antioxidant compounds that enhance plant metabolic activity and physiological efficiency, which may indirectly support flower retention and fruit development. Therefore, the marked increase in fruit set and retention percentages recorded in the current study could be explained by the synergistic effect of *Spirulina*-derived nutrients and growth-promoting compounds on reproductive processes and assimilating distribution within Valencia orange trees.

Table 1. Effect of foliar spraying with *Spirulina platensis* extract on fruit set% and fruit retention% of Valencia orange trees during 2022 and 2023 seasons

Treatments	Fruit Set %		Fruit retention %	
	S1	S2	S1	S2
Control	24.58 ^c	21.75 ^d	2.32 ^d	2.38 ^d
Spirulina 1ml/L	30.89 ^b	27.64 ^c	3.06 ^c	3.14 ^c
Spirulina 2ml/L	34.24 ^b	36.49 ^b	3.88 ^b	3.93 ^b
Spirulina 3ml/L	39.36 ^a	40.15 ^{ab}	4.38 ^a	4.57 ^a

Spirulina 4ml/L	41.83 ^a	44.56 ^a	4.85 ^a	4.90 ^a
LSD 5%	4.29	4.43	0.48	0.49

Effect of spraying with *Spirulina platensis* extract on yield parameters

The data presented in Table (2) clearly indicate that foliar application of *Spirulina platensis* extract significantly enhances the productivity of Valencia orange trees. The highest values were recorded with the 4 ml/L treatment, which produced 65.60 kg of fruit per tree and a total yield of 11.02 tons per feddan during the second season. From a statistical perspective, the higher concentrations (3 and 4 ml/L) consistently outperformed the control treatment. This improvement can be attributed to the rich composition of *Spirulina*, including essential nutrients and natural growth regulators that enhance photosynthetic efficiency and promote fruit development. These results agree with previous studies (**Kapooore et al., 2021 and Prisa et al., 2024**), which highlighted the effectiveness of algae-based biostimulants in enhancing crop productivity and improving citrus yield and fruit quality. Moreover, the beneficial role of amino acids and signaling compounds in enhancing nutrient translocation, metabolic activity, and productivity stability has been widely documented in studies on plant bio stimulants (**Calvo et al., 2014 and Colla et al., 2017**).

Interestingly, the cropping efficiency values show a decreasing trend as the concentration of *Spirulina* increases. This is a common physiological observation where, although total yield increases, the ratio of yield to the vegetative volume (efficiency) may level off or decrease as the tree invests more energy into overall biomass and fruit weight

The obtained results in Table (2) clearly demonstrate that foliar application of *Spirulina platensis* extract had a significant positive effect on yield components of Valencia orange trees (*Citrus sinensis*) during the two experimental seasons (2022 and 2023). The increase in fruit weight per tree and total yield per feddan, particularly under the highest concentration (4 ml/L), indicates a clear concentration-dependent response, where higher levels of *Spirulina* extract resulted in superior productivity compared with the control and lower concentrations.

These findings are in agreement with **Ismaiel and Ismail (2024)**, who reported that foliar application of seaweed extracts significantly enhanced yield and fruit quality of Valencia orange trees, with higher concentrations showing the most effective response. Similarly, **Alebidi and Abdel-Sattar (2024)** confirmed that the use of seaweed-based bio stimulants improves productivity and fruit physio-chemical properties in Valencia orange, emphasizing the role of algal extracts in enhancing citrus performance under field conditions.

The observed improvement in yield parameters may be attributed to the rich composition of *Spirulina platensis* extract, which contains essential nutrients, amino acids, vitamins, and growth-promoting substances such as phytohormones. These bioactive compounds enhance physiological processes including photosynthesis, nutrient uptake efficiency, and carbohydrate accumulation, ultimately leading to improved fruit development and yield.

Moreover, **Galal et al. (2024)** reported that macroalgae extracts enhance metabolic activity and assimilate translocation in citrus trees, resulting in increased fruit set, fruit weight, and overall yield. The superiority of higher concentrations (3 and 4 ml/L) observed in the present study further supports the concept that an optimal level of bio stimulant application is required to maximize physiological and productive responses in citrus trees.

Table 2. Effect of foliar spraying with *Spirulina platensis* extract on yield as fruit number and weight/tree of Valencia orange trees during 2022 and 2023 seasons

Treatments	Number of fruits/ tree		Yield (kg/tree)		Yield (Ton/fed.)		Fruiting efficiency	
	S1	S2	S1	S2	S1	S2	S1	S2
Control	251.75 ^c	344.23 ^b	44.06 ^c	45.00 ^c	7.40 ^c	7.56 ^c	3.82 ^a	3.78 ^a

Spirulina 1ml/L	279.29 ^{bc}	338.14 ^b	49.54 ^c	46.71 ^c	8.32 ^c	7.85 ^c	3.22 ^{ab}	3.00 ^{ab}
Spirulina 2ml/L	308.12 ^{ab}	321.52 ^a	55.63 ^b	58.44 ^b	9.34 ^b	9.82 ^b	3.15 ^{ab}	2.91 ^{ab}
Spirulina 3ml/L	334.12 ^a	265.79 ^a	62.37 ^a	63.08 ^{ab}	10.47 ^a	10.60 ^{ab}	2.97 ^{ab}	2.72 ^{ab}
Spirulina 4ml/L	341.43 ^a	258.86 ^a	64.98 ^a	65.60 ^a	10.91 ^a	11.02 ^a	2.27 ^b	2.18 ^b
LSD 5%	39.16	39.43	5.85	5.89	0.98	0.98	1.34	1.25

Effect of spraying with *Spirulina platensis* extract on fruit physical characteristics

The data presented in Table 3 illustrates the significant influence of foliar spraying with *Spirulina platensis* extract on the physical characteristics of Valencia orange fruits during the 2022 (S1) and 2023 (S2) seasons. The application of *Spirulina* extract led to a progressive and significant increase in almost all physical parameters compared to the untreated control. The 4 ml/L treatment consistently recorded the highest values, with fruit weight reaching 190.72 gm and volume reaching 191.21 cm³ in S2. This represents a substantial increase over the control (173.84 gm and 174.73 cm³, respectively). Both dimensions showed significant expansion under higher concentrations. The fruit length peaked at 8.13 cm and width at 7.16 cm with the 4 ml/L dose. Accordingly, both 3 ml/L and 4 ml/L concentrations were statistically superior, indicating they are the most effective doses for enhancing fruit size. Interestingly, the shape index remained relatively constant across all treatments (ranging from 1.09 to 1.17) and showed no significant differences. This indicates that while the fruit grew larger and heavier, it maintained its characteristic oval/round shape.

The enhancement of fruit physical traits following *Spirulina* application may be attributed to its richness in hormone-like compounds, particularly auxins and cytokinins, which stimulate cell division and enlargement in fruit tissues, thereby increasing fruit size and weight (Khan *et al.*, 2009; Taiz *et al.*, 2015). In addition, the improvement in vegetative vigor and leaf area enhances photosynthetic capacity and promotes assimilate translocation from source leaves to developing fruits, ensuring an adequate carbohydrate supply for fruit enlargement and biomass accumulation (Iglesias *et al.*, 2007; Goldschmidt and Koch, 1996; Pérez-Pérez *et al.*, 2014). Moreover, the presence of essential minerals (K, P, Zn) and amino acids in the extract play a vital role in maintaining cell turgor and structural integrity during the fruit enlargement phase.

The results are in close agreement with modern research on algae-based bio-stimulants in citrus, as such (Khan *et al.*, 2009; Ronga *et al.*, 2019) confirms that cyanobacterial and algal bio stimulants significantly enhance fruit weight and dimensions through improving nutrient assimilation, photosynthetic performance, and metabolic efficiency in horticultural crops. Moreover, Rouphael and Colla, 2020; Khan *et al.*, 2009 found that Bioactive molecules present in *Spirulina* biomass may act as natural catalysts for nutrient uptake and metabolic activity, thereby enhancing fruit growth and increasing fruit volume and weight. Furthermore, the stability of the fruit shape index despite the increase in fruit size suggests a balanced hormonal and physiological influence of the applied bio stimulant. Previous studies have indicated that natural bio stimulants provide a more balanced stimulation of plant growth than synthetic growth regulators, thereby enhancing fruit quality while maintaining normal fruit shape and commercial characteristics (Rouphael and Colla, 2020; du Jardin, 2015). It can be concluded that foliar application of *Spirulina platensis* extract at 4 ml/L is the optimum treatment for improving the physical quality of Valencia oranges. This treatment results in larger, heavier fruits that meet higher market standards while maintaining the natural shape index of the variety.

Data in Table 3 clearly shows that foliar application of *Spirulina platensis* extract significantly improves the physical characteristics of Valencia orange fruits. The 4 ml/L treatment consistently recorded the highest values for both fruit weight (190.72 g) and volume (191.21 cm³). Statistical analysis using LSD at the 5% level confirms that the higher concentrations (3 and 4 ml/L) are more effective in increasing fruit length and width, while maintaining a stable fruit shape index. This enhancement may be attributed to the presence of hormone-

like substances in *Spirulina*, particularly auxins and cytokinin's, which stimulate cell enlargement and improve assimilate translocation from source leaves to developing fruits. Consequently, fruit growth and quality are significantly enhanced. Similar findings were reported in previous studies on algal bio stimulants, which demonstrated positive effects on fruit quality attributes and maintenance of desirable commercial fruit characteristics (Ali *et al.*, 2021; Rouphael and Colla, 2020).

Table 3. Effect of foliar spraying with *Spirulina platensis* extract of fruit physical characteristics of Valencia orange trees during 2022 and 2023 seasons

Treatments	Fruit weight (g)		Fruit volume (cm ³)		Fruit length (cm)		Fruit width (cm)		Fruit shape index	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Control	175.03 ^c	173.84 ^c	175.14 ^d	174.73 ^c	7.15 ^c	7.20 ^c	6.34 ^c	6.13 ^c	1.13 ^a	1.17 ^a
Spirulina 1ml/L	177.50 ^{bc}	175.86 ^c	177.84 ^{cd}	176.43 ^c	7.41 ^{bc}	7.37 ^{bc}	6.74 ^b	6.60 ^b	1.09 ^a	1.11 ^a
Spirulina 2ml/L	180.77 ^b	181.98 ^b	181.22 ^c	182.47 ^b	7.96 ^{ac}	7.56 ^{bc}	6.98 ^{ab}	6.75 ^b	1.10 ^a	1.12 ^a
Spirulina 3ml/L	186.70 ^a	186.60 ^a	187.23 ^b	187.60 ^a	7.89 ^{ab}	7.85 ^{ab}	7.11 ^{ab}	6.85 ^{ab}	1.11 ^a	1.14 ^a
Spirulina 4ml/L	190.46 ^a	190.72 ^a	191.57 ^a	191.21 ^a	8.09 ^a	8.13 ^a	7.25 ^a	7.16 ^a	1.12 ^a	1.14 ^a
LSD 5%	4.15	4.15	4.16	4.16	0.58	0.57	0.39	0.38	0.11	0.11

Data in Table 4 indicates a positive and progressive correlation between the concentration of *Spirulina platensis* foliar spray and the physical quality parameters of Valencia oranges. As the concentration increased from 1 ml/L to 4 ml/L, there was a significant enhancement in pulp weight, peel weight, peel thickness, and firmness compared to the control group in both the 2022 (S1) and 2023 (S2) seasons.

The highest concentration (4 ml/L) yielded the maximum pulp weight (174.14 g in S1 and 171.85 g in S2), significantly outperforming the control. This suggests that *Spirulina* extract, which is rich in amino acids, vitamins, and minerals, promotes better nutrient assimilation and cell division in the fruit juice sacs.

Similarly, peeling weight increased significantly, nearly doubling in value from the control to the 4 ml/L treatment. There is a clear trend where *Spirulina* treatments led to thicker peels. Thicker peels are often scientifically associated with reduced moisture loss and better protection against mechanical damage during transport. This is one of the most critical findings. The firmness increased from 5.33 (Control) to 8.90 (4 ml/L) in S1. Higher firmness indicates a delay in fruit senescence and improved post-harvest shelf life, likely due to the role of algal extracts in strengthening cell walls. In almost all parameters, the 3 ml/L and 4 ml/L treatments showed no significant difference between each other but were significantly superior to the control and the 1 ml/L dose.

The results are highly consistent across S1 (2022) and S2 (2023). This reproducibility strengthens the reliability of the findings, suggesting that the bio stimulant effect of *Spirulina* is stable regardless of slight seasonal climatic variations.

Results in Table 4 clearly demonstrated that foliar application of *Spirulina platensis* extract markedly improved the physical characteristics of Valencia orange fruits during both experimental seasons. The superiority of the higher concentrations (3 and 4 ml/L) in increasing pulp weight, peel weight, peel thickness, and fruit firmness may be attributed to the rich biochemical composition of *Spirulina platensis*, which contains considerable amounts of amino acids, vitamins, minerals, proteins, natural phytohormones, antioxidants, and growth-promoting substances. These bioactive compounds play a vital role in enhancing cell division, cell enlargement, nutrient uptake, and carbohydrate accumulation, consequently improving fruit growth and structural integrity.

The observed increase in fruit firmness and peel thickness could also be associated with the positive effect of *Spirulina* extract on strengthening cell wall components and enhancing calcium and potassium translocation within fruit tissues, which contributes to improving fruit texture and postharvest tolerance. Furthermore, the enhancement in pulp and peel weight may reflect the stimulatory role of algal extracts in promoting photosynthetic efficiency and assimilate translocation toward developing fruits.

These findings agree with those reported by **Emine Seğmen and Halime Özdamar Ünlü (2023)**, who found that foliar spraying with *Spirulina platensis* extract significantly improved fruit quality parameters in pepper plants, including fruit size, firmness, and yield components. Likewise, the present results are consistent with the findings of **Amro (2015)**, who reported that algae extract application enhanced fruit weight, fruit size, peel characteristics, and overall fruit quality of Valencia orange trees.

In addition, similar improvements in physical fruit properties following algae or seaweed extract application were observed by **Mohammed Al-Musawi (2018)** on sour orange fruits, where algae extract significantly increased fruit fresh weight, peel thickness, and fruit quality traits compared with untreated trees. Furthermore, recent studies on Valencia orange **Hoda Galal et al (2024)** and **Alebidi and Abdel-Sattar (2024)**, confirmed that foliar application of seaweed-based bio stimulants improved fruit physical properties such as fruit weight, pulp weight, peel weight, and firmness due to enhanced nutritional and physiological status of Valencia orange fruits.

Table 4. Effect of foliar spraying with *Spirulina platensis* extract on fruit pulp and peel weight, peel thickness and firmness of Valencia orange trees during 2022 and 2023 seasons

Treatments	Pulp weight (g)		Peel weight (g)		Peel thickness (mm)		Fruit firmness (kg/inch ²)	
	S1	S2	S1	S2	S1	S2	S1	S2
Control	132.99 ^c	139.27 ^d	24.38 ^d	24.83 ^d	2.62 ^c	2.59 ^c	5.33 ^d	5.26 ^c
Spirulina 1ml/L	147.07 ^b	142.11 ^{cd}	28.36 ^c	29.18 ^c	2.90 ^c	2.70 ^c	6.58 ^c	6.60 ^b
Spirulina 2ml/L	156.77 ^b	152.58 ^{bc}	34.88 ^b	37.74 ^b	3.50 ^{bc}	3.78 ^b	7.62 ^b	7.04 ^b
Spirulina 3ml/L	169.49 ^a	161.34 ^{ab}	40.62 ^a	41.03 ^a	4.25 ^{ab}	4.37 ^{ab}	8.43 ^a	8.73 ^a
Spirulina 4ml/L	174.14 ^a	171.85 ^a	42.01 ^a	42.41 ^a	4.63 ^a	4.80 ^a	8.90 ^a	9.20 ^a
LSD 5%	10.68	10.52	1.39	1.42	0.89	0.93	0.51	0.51

Effect of spraying with *Spirulina platensis* extract on fruit chemical characteristics

Data in Table 5 illustrates that foliar application of *Spirulina platensis* extract significantly improved the fruit chemical characteristics of Valencia orange trees during the 2022 and 2023 seasons. There is a clear dose-dependent increase in Total Soluble Solids (TSS), Acidity, and Vitamin C content as the concentration of *Spirulina* increases from 1 ml/L to 4 ml/L.

As for, total soluble solids (TSS) and Vitamin C, the highest values were consistently recorded at the 4 ml/L concentration, which yielded TSS values of 13.38% and 13.80% and Vitamin C levels of 61.30 and 62.02 mg/100g for S1 and S2, respectively. Statistically, the 3 ml/L and 4 ml/L treatments often share the same highest significant values, indicating that while they are both significantly superior to the control, the difference between these two high-dose treatments is not always statistically significant. As for acidity and TSS/Acid Ratio. Interestingly, increasing the *Spirulina* concentration led to a significant rise in fruit acidity, which consequently resulted in a reduction in the TSS/Acid ratio compared to the control. The control group maintained the highest TSS/Acid ratio (14.21 and 15.72) because it had the lowest acidity levels.

These improvements in fruit chemical quality are attributed to the rich biochemical composition of *Spirulina*, which enhances plant metabolism, carbohydrate synthesis, nutrient uptake, and antioxidant activity. The increase in TSS agrees with previous reports in citrus where algal extracts improved sugar accumulation and fruit quality

through enhanced photosynthesis and assimilate translocation **Mohamed Al-Musawi (2018)**. Similarly, the enhancement in vitamin C content could be attributed to the antioxidant activity of *Spirulina*-based bio stimulants, which promote ascorbic acid biosynthesis and reduce oxidative degradation in plant tissues, thereby improving fruit nutritional quality (**Salama et al., 2021; Bulgari et al., 2019**). Although acidity also increased, leading to a lower TSS/acid ratio, this reflects a balanced improvement in sugars and organic acids that enhances fruit flavor and biochemical stability. The highest responses at 4 ml/L, with no significant difference from 3 ml/L, indicate that moderate concentrations are sufficient to achieve optimal fruit quality. Overall, *Spirulina* acts as an effective natural bio stimulant for improving citrus fruit quality by enhancing primary metabolism, antioxidant systems, and nutrient assimilation.

Table 5. Effect of foliar spraying with *Spirulina platensis* extract on fruit chemical characteristics of Valencia orange trees during 2022 and 2023 seasons

Treatments	TSS		Acidity		TSS/ acid ratio		Vit. C	
	S1	S2	S1	S2	S1	S2	S1	S2
Control	10.90 ^d	10.55 ^d	0.77 ^c	0.67 ^d	14.21 ^a	15.72 ^a	55.80 ^c	56.10 ^c
Spirulina 1ml/L	11.31 ^c	11.04 ^c	0.83 ^{bc}	0.79 ^c	13.55 ^{ab}	13.89 ^b	56.82 ^c	57.79 ^b
Spirulina 2ml/L	12.66 ^b	11.39 ^b	0.92 ^b	0.98 ^b	13.73 ^{ab}	11.63 ^c	58.78 ^b	58.39 ^b
Spirulina 3ml/L	13.21 ^a	13.54 ^a	1.06 ^a	1.01 ^{ab}	12.48 ^{bc}	13.44 ^b	60.04 ^{ab}	60.78 ^a
Spirulina 4ml/L	13.38 ^a	13.80 ^a	1.18 ^a	1.11 ^a	11.40 ^c	12.46 ^{bc}	61.30 ^a	62.02 ^a
LSD 5%	0.28	0.27	0.11	0.11	1.37	1.44	1.33	1.34

Data in Table 6 illustrates a significant metabolic enhancement in Valencia orange fruits as a result of *Spirulina platensis* foliar applications. There is a clear upward trend in all measured biochemical parameters, indicating that the algal extract stimulates the synthesis and accumulation of sugars and carbohydrates.

The extract increased reducing sugar percentages, peaking at 8.47%–8.57% with the 4 ml/L treatment. This suggests an increase in the primary metabolic products of photosynthesis. Moreover, non-reducing sugars with the 4 ml/L dose reaching 4.93%–5.14%. This suggests that the extract enhances the translocation of sucrose and other complex sugars from the leaves to the fruit sink. The total carbohydrate percentage reached a maximum of 14.74% in S1. Scientifically, this increase is likely due to *Spirulina's* rich content of growth-promoting substances (like auxins and cytokinin's) and micronutrients that catalyze the enzymatic pathways involved in starch and sugar biosynthesis. The increase in total sugars (13.40%–13.72% at the highest dose vs. ~10.9% in control) directly impacts the TSS (Total Soluble Solids) and the sweetness of the fruit, which are primary commercial quality indicators for Valencia oranges.

Statistical analysis at the 5% level shows that the 4 ml/L concentration is the most effective treatment, While the 1 ml/L and 2 ml/L treatments provided some improvements, they often shared statistical groups with the control. However, the 3 ml/L and 4 ml/L doses showed a clear statistical separation from the control across all parameters.

The data shows high reproducibility between S1 (2022) and S2 (2023). The fact that the bio stimulant maintains its efficacy over two consecutive years indicates its reliability as a consistent agricultural input for improving fruit chemical composition.

Results in Table 6 clearly demonstrate that foliar spraying with *Spirulina platensis* extract significantly enhanced reducing sugars, non-reducing sugars, total sugars, and total carbohydrate contents of Valencia orange fruits during both experimental seasons. The superiority of the higher concentrations, especially 4 ml/L, may be attributed to the bio stimulatory properties of *Spirulina platensis*, which is naturally rich in amino acids, proteins, vitamins, minerals, antioxidants, and growth-promoting substances. These compounds are known to stimulate photosynthetic activity, enhance chlorophyll biosynthesis, and improve nutrient assimilation, leading

to greater synthesis and accumulation of carbohydrates within fruit tissues. The increase in total sugars and carbohydrates observed in the present study may also result from improved translocation of photo assimilates from leaves to fruits, in addition to enhanced enzymatic activities involved in carbohydrate metabolism. The improved nutritional status of treated trees, particularly the increased potassium and magnesium concentrations, contributed to greater photosynthetic efficiency and sucrose transport, ultimately enhancing fruit sweetness and internal quality.

These findings are consistent with those reported by **Seğmen and Özdamar Ünlü (2023)**, who found that foliar application of *Spirulina platensis* extract significantly improved fruit quality parameters and soluble solids accumulation in pepper fruits. The authors attributed these improvements to enhanced physiological and metabolic activities induced by *Spirulina* bioactive compounds. Similarly, **Salama (2015)** reported that algae extract treatments enhanced fruit quality characteristics and biochemical constituents of Valencia orange fruits through stimulation of photosynthesis and nutrient uptake.

In addition, **Shabana et al. (2017)** demonstrated that *Spirulina platensis* contains high levels of biologically active compounds, antioxidants, and essential nutrients capable of improving plant metabolic performance and physiological processes associated with carbohydrate biosynthesis. Furthermore, **(Salama et al., 2021 and Ronga et al., 2019)** confirmed that *Spirulina platensis* contains abundant phytonutrients, pigments, amino acids, and antioxidant compounds that enhance photosynthetic metabolism and promote carbohydrate accumulation in plants.

Table 6. Effect of foliar spraying with *Spirulina platensis* extract on reducing, non-reducing and total sugar and total carbohydrates% on fruits of Valencia orange trees during 2022 and 2023 seasons

Treatments	Reducing sugar %		Non reducing sugar %		Total sugar %		Total Carbohydrates %	
	S1	S2	S1	S2	S1	S2	S1	S2
Control	7.26 ^b	7.37 ^b	3.67 ^d	3.62 ^b	10.93 ^c	10.99 ^c	11.59 ^c	11.25 ^c
Spirulina 1ml/L	7.54 ^b	7.66 ^b	3.89 ^{cd}	3.77 ^b	11.43 ^{bc}	11.43 ^{bc}	12.38 ^{bc}	12.76 ^{bc}
Spirulina 2ml/L	7.66 ^{ab}	7.75 ^{ab}	4.38 ^{bc}	4.69 ^a	12.05 ^{ac}	12.45 ^{ab}	13.67 ^{ab}	13.64 ^{ab}
Spirulina 3ml/L	8.10 ^{ab}	8.26 ^{ab}	4.45 ^{ab}	4.99 ^a	12.56 ^{ab}	13.25 ^a	14.38 ^a	14.11 ^{ab}
Spirulina 4ml/L	8.47 ^a	8.57 ^a	4.93 ^a	5.14 ^a	13.40 ^a	13.72 ^a	14.74 ^a	14.45 ^a
LSD 5%	0.89	0.90	0.50	0.54	1.39	1.45	1.57	1.54

5. Conclusion

In general, the present study confirms that foliar application of *Spirulina platensis* extract is an effective, safe, and environmentally friendly natural bio-stimulant for improving productivity and fruit quality of Valencia orange trees.

References

- [1] **A.O.A.C. (2006)**. Association of Official Agricultural Chemists. Official Methods of Analysis. 5th ed. pp. 495- 510. Benjamin Franklin Station, Washington. D.C., U.S.A.
- [2] **Abdel-Mawgoud, A. M. R., Tantaway, A. S., Hafez, M. M., and Habib, H. A. M. (2010)**. Seaweed extract improves growth and quality of horticultural crops. Research Journal of Agriculture and Biological Sciences, 6(2), 161–168.
- [3] **Ahmed, E.F.S.; Mohamed, H.H.S. and Gad Alla ,E.G. (2011)**: Effect of some vitamins on fruiting of Zaghloul date palms. Minia J. of Agric. Res .andDevelop. 31(3): 371-381.
- [4] **Alebidi, A. and Abdel-Sattar M. (2024)**. Synergistic effect of seaweed extract and boric acid and/or calcium chloride on productivity and physio-chemical properties of Valencia orange. PeerJ., 12, e17378.
- [5] **Ali, O., Ramsuhag, A., and Jayaraman, J. (2021)**. Biostimulatory activities of seaweed extracts and plant growth promoting microorganisms in vegetable transplantation. Scientia Horticulturae, 196, 1–14.
- [6] **Aly-Samar, S.H. (2015)**. 'Influence of reducing mineral nitrogen fertilizer partially by using plant compost enriched with spirulina platensis algae fruiting of Flame seedless grapevines' M.Sc., Thesis. Fac. of Agric. Minia Univ.

- [7] **Amro Salama Mohamed Salama (2015)**. Effect of Algae Extract and Zinc Sulfate Foliar Spray on Production and Fruit Quality of Orange Tree cv. Valencia. *IOSR Journal of Agriculture and Veterinary Science*, 8(9), 51–62.
- [8] **Awad, E. M., Youssef, N. S., and Shall, Z. S. (2006)**. Effect of foliar spraying seaweed extracts and inorganic fertilizer levels on growth, yield and quality of potato crops. *Journal of Plant Production*, 31(10), 6549-6556.
- [9] **Barron, L.B., Torres- Valencia, M.K., Chamorro-Cevallos, G. and Zooiga Estrada, A. (2008)** Spirulina as an Antiviral Agent, in M.E. Gershwin and Amha Belay (ed.) *Spirulina in human nutrition and health*, CRC press, Taylor and Francis, pp. 227.
- [10] **Barron, L.B., Torres- Valencia, M.K., Chamorro-Cevallos, G. and Zooiga Estrada, A. (2008)** Spirulina as an Antiviral Agent, in M.E. Gershwin and Amha Belay (ed.) *Spirulina in human nutrition and health*, CRC press, Taylor and Francis, pp. 227.
- [11] **Bulgari, R., Franzoni, G., and Ferrante, A. (2019)**. Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy*, 9(6), 306.
- [12] **Calvo, P., Nelson, L., and Kloepper, J. W. (2014)**. Agricultural uses of plant biostimulants. *Plant and Soil*, 383, 3–41.
- [13] **Ciferri, O and Tibani, O. (1985)** The biochemistry and industrial potential of Spirulina' *Ann. Rev. Microb.* 39: 503 – 526.
- [14] **Colla, G., Hoagland, L., Ruzzi, M., Cardarelli, M., Bonini, P., Canaguier, R., and Roupael, Y. (2017)**. Biostimulant action of protein hydrolysates: Unraveling their effects on plant physiology and microbiome. *Frontiers in Plant Science*, 8, 2202.
- [15] **du Jardin, P. (2015)**. Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae*, 196, 3–14.
- [16] **Emine Seğmen and Halime Özdamar Ünlü (2023)**. Effects of foliar applications of commercial seaweed and Spirulina platensis extracts on yield and fruit quality in pepper (*Capsicum annuum* L.). *Cogent Food and Agriculture*, 9(1), 2233733. <https://doi.org/10.1080/23311932.2023.2233733>
- [17] **Galal, H. A., El-Sayed, S. A., Abdel-Aziz, N. G., and Mohamed, A. A. (2024)**. Effect of foliar application of macroalgae extracts on Valencia orange. *Egyptian Journal of Botany*, 64(3), 16–28.
- [18] **Goldschmidt, E., and Koch, K. (1996)**. Citrus. In 'Photo assimilate distribution in plants and crops'. (Eds E Zamski, A Schaffer) pp. 797–823.
- [19] **Hashtroudi, M.S., A. Ghassempour, H. Riahi, Z. Shariatmadari, M. Khanjir,(2013)**. Endogenous auxin in plant growth promoting Cyanobacteria-Anabaena vaginicola and Nostoc calcicola, *J. Appl. Phycol.* 25: 379–386.
- [20] **Henrikson, R., (2010)**. Spirulina: World Food, how these micro algae can transform your health and our planet, Published by Ronore Enterprises, Inc. PO Box 909, Hana, Maui, Hawaii 96718 USA, pp.195.
- [21] **Hoda Galal, Enas Azzam, Mohamed El-Howeity and Ashraf Nofal (2024)**. Effect of Foliar Application of Macroalgae Aqueous Extracts on the Nutrient Status and Fruit Quality of Valencia Orange. *Egyptian Journal of Botany*, 64(3), 16–28. <https://doi.org/10.21608/ejoh.2023.213742.1248>
- [22] **Hussien, M. A. (2017)**. 'Productive Performance of Sewy Date Palms in Relation to Spraying Spirulina Platensis Algae, Plant Compost Tea, Salicylic Acid and Tocopherol' *New York Science Journal*; 10(7): 126 – 135.
- [23] **Iglesias, D. J., Cercós, M., Colmenero-Flores, J. M., Naranjo, M. A., Ríos, G., Carrera, E., ... and Talon, M. (2007)**. Physiology of citrus fruiting. *Brazilian Journal of Plant Physiology*, 19(4), 333-362.
- [24] **Ismail, H. M. H., and Ismail, H. S. H. (2024)**. Effect of spraying some amino acids and seaweed extract on the yield and quality fruits of Valencia orange. *Egyptian Journal of Horticulture*, 51(2), 151–160.
- [25] **Kapooore, R. V., Wood, E. E., and Llewellyn, C. A. (2021)**. Algae biostimulants: A critical look at microalgal biostimulants for sustainable agricultural practices. *Biotechnology Advances*, 49, 107754.
- [26] **Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., Critchley, A. T., Craigie, J. S., Norrie, J., and Prithiviraj, B. (2009)**. Seaweed extracts as biostimulants of plant growth and development. *Journal of Plant Growth Regulation*, 28, 386–399.
- [27] **Kumar, A., Ramamoorthy, D., Verma, D. K., Kumar, A., Kumar, N., Kanak, K. R. and Mohan, K. (2022)**. Antioxidant and phytonutrient activities of Spirulina platensis. *Energy Nexus*, 6, 100070.
- [28] **Lane, J.H. and L. Eynon (1965)**. Determination of reducing sugars by means of Fehling's solution with methylene blue as indicator A.O.A.C. Washington D.C.U.S.A. pp: 490-510.
- [29] **Mohammed Al-Musawi (2018)**. Effect of Foliar Application with Algae Extracts on Fruit Quality of Sour Orange (*Citrus aurantium* L.). *Journal of Environmental Science and Pollution Research*, 4(1), 250–252.
- [30] **Nour, K. A. M., Mansour, N. T. S., and Abd El-Hakim, W. M. (2010)**. Influence of foliar spray with seaweed extracts on growth, setting and yield of tomato during summer season. *Journal of Plant Production*, 1(7), 961–976.
- [31] **Pérez-Pérez, J. G., Robles, J. M., and Botía, P. (2014)**. Effects of deficit irrigation in different fruit growth stages on 'Star Ruby' grapefruit trees in semi-arid conditions. *Agricultural Water Management*, 133, 44-54.
- [32] **Pramanick, B., Brahmachari, K., and Ghosh, A. (2013)**. Effect of seaweed saps on growth and yield improvement of green gram. *African Journal of Agricultural Research*, 8(13), 1180–1186.
- [33] **Prisa, D., Fresco, R., Jamal, A., Saeed, M. F., and Spagnuolo, D. (2024)**. Exploring the potential of macroalgae for sustainable crop production in agriculture. *Life*, 14(10), 1263.

- [34] Ronga, D., Biazzi, E., Parati, K., Carminati, D., Carminati, E., and Tava, A. (2019). Microalgal biostimulants and biofertilisers in crop productions. *Agronomy*, 9(4), 192.
- [35] Roupghael, Y., and Colla, G. (2020). Biostimulants in agriculture. *Frontiers in Plant Science*, 11, 40.
- [36] Salama, A. S. M. (2015). Effect of Algae Extract and Zinc Sulfate Foliar Spray on Production and Fruit Quality of Orange Tree cv. Valencia. *IOSR Journal of Agriculture and Veterinary Science*, 8(9), 51–62.
- [37] Salama, D. M., Abd El-Aziz, M. E., Rizk, F. A., and Abd Elwahed, M. S. A. (2021). Applications of algae and cyanobacteria in biostimulation, biofertilization and biocontrol in sustainable agriculture. *Applied Sciences*, 11(23), 11460.
- [38] Seğmen, E., and Özdamar Ünlü, H. (2023). Effects of foliar applications of commercial seaweed and *Spirulina platensis* extracts on yield and fruit quality in pepper (*Capsicum annuum* L.). *Cogent Food and Agriculture*, 9(1), 2233733. <https://doi.org/10.1080/23311932.2023.2233733>
- [39] Shabana, E. F., Gabr, M. A., Moussa, H. R., El-Shaer, E. A., and Ismaiel, M. M. S. (2017). Biochemical composition and antioxidant activities of *Arthrospira* (*Spirulina*) *platensis* in response to gamma irradiation. *Food Chemistry*, 214, 550–555. <https://doi.org/10.1016/j.foodchem.2016.07.109>
- [40] Shalaby, T. A., and El-Ramady, H. (2014). Effect of foliar application of bio stimulants on growth, yield, yield components, and storability of garlic (*Allium sativum* L.). *AJCS*, 8(2), 271–275.
- [41] Snedecor, G.W., and W.G. Cochran (1980). *Statistical Methods* 7th edition, Iowa Astateuni. Press, Ames, Iowa.
- [42] Spinelli, F., Giovanni, F., Massimo, N., Mattia, S., and Guglielmo, C. (2009). Perspectives on the use of a seaweed extract to moderate the negative effects of alternate bearing in apple trees. *The Journal of Horticultural Science and Biotechnology*, 84(6), 131- 37
- [43] **Statistics of the Ministry of Agriculture (2024)**. Statistics of fruit production.
- [44] Taiz, L., Zeiger, E., Møller, I. M., and Murphy, A. (2015). *Plant Physiology and Development* (6th ed.). Sinauer Associates.
- [45] Vonshak, A. and A. Richmond (1985). Mass production of blue-green algae *Spirulina*. An Overview. *Biomass*, 15: 233-247.
- [46] Vonshak, A. (1986). Laboratory techniques for the cultivation of microalgae. In *Handbook of Microalgal Mass Culture*, ed. A. Richmond, pp: 117 – 45 Boca Raton: CRC Press.