

The Role of Melatonin, Boron and the Addition of Algae *Chlorella Vulgaris* in Growth and Yield of Date Palm, (Cv. Al-Sayer) Under Conditions of Environmental Stress

Mustafa E. Al-Asally* and Salah H. J. Al-Hchami

Department of Horticulture and Landscape Gardening, College of Agricultural engineering sciences, University of Baghdad, Baghdad, Iraq.

*Corresponding Author E-mail: mostafa.isam1205a@coagri.uobaghdad.edu.iq

Abstract

The experiment was conducted in the Fadak palm farm located in the desert of Karbala city, where 54 growth-homogeneous date palms, seven years old (Al-Sayer variety), were chosen. Boron (Boric acid) was sprayed at two concentrations (0 and 500 mg/L) three times, and Melatonin was sprayed at three concentrations (0, 50, and 100 mg/L) during three stages. *Chlorella vulgaris* algae were added to the soil at three concentrations (0, 100, and 200 mL/L) at a rate of five liters per tree five times from January to May with one addition monthly. Spraying Melatonin spraying increased the fruit content of total phenolics and carotenoids, and spraying Boron led to an increase in the fruit maturity percentage and total yield, and the addition of algae led to an increase in phosphorus in the palm leaves. And all additions improved the qualitative and chemical characteristics and the total production of the date palm trees. The experiment aims to determine the effect of Melatonin, Boron, and *Chlorella vulgaris* algae addition on the growth and production of date palms under conditions of environmental stress.

Keywords: Boron, Melatonin, Biofertilization, Environmental Stress

Introduction

Melatonin, a newly identified hormone in plants, can be used to control the biological clock and improve plants' resistance against environmental stresses. It has been recently demonstrated that melatonin plays many biological roles, which include regulation of plant growth, seed germination stimulation root development control leaf senescence retardation. In addition, it interacts synergistically with other hormones, especially auxins. The more typical characteristic of melatonin is that it has the astonishing ability to elevate the activities of antioxidant enzymes, which can increase resistance of heat and drought stress in plant (Zeng et al., 2022; Arnao and Hernández-Ruiz, 2021).

Boron (B) is an essential and necessary element for the physiological performance of plants, and its deficiency indicates poor plant growth (Pereira et al., 2021). Boron is involved in the structural and functional integrity of the cell wall and membranes, the flow of (H⁺) ions across membranes, cell division and cell elongation, and its important role in carbohydrate transport (Shireen et al., 2018), and the transport of sugar and structural cytoskeletal proteins. Boron also has a relationship with plant hormones like auxins and cytokinins and plays an important role in fertilization processes as it aids in pollen tube elongation, thereby increasing the fruit set percentage and consequently increasing the total yield (Shaker, and Rasool, 2023; Al-Naqeeb et al., 2010; Sadiq, 2023).

Biofertilization is one of the most important sustainable agricultural practices, involving the use of biofertilizers to increase the soil's content of essential nutrients, leading to increased productivity (Mitter et al., 2021). The importance of microalgae in soil for improving its fertility and increasing the biomass productivity of the soil microbial community has been identified, and it has been designated as an environmentally friendly, feasible algal biofertilizer for pollution-free cultivation. *Chlorella* algae are among the most commonly used species in biofertilizers due to their ability to adapt quickly in soil, requiring moderate moisture and high light conditions to achieve the maximum number of cell divisions, which increases their mass within the soil. They then decompose to release important nutrients into the soil, facilitating their absorption by the roots (Abinandan et al., 2019). The date palm (*Phoenix dactylifera* L.) is one of the most important perennial, evergreen fruit trees known to man, belonging to the Arecaceae family and the order Arecales; it is a monocot plant. Among the most important characteristics of the date palm tree is its adaptation to dry desert conditions, as it is one of the most drought-resistant trees, tolerant of high temperatures as well as soil and irrigation water salinity. Sayer is considered a major cultivar for its early maturity, good quality fruits and resistance to diseases, hence it has been the focus of extensive research (AL- Bekr 1972).

Materials and Methods

The experiment was carried out at the Fadak Date Palm Farm, located in the western desert of Karbala city, according to the coordinates (32.722086, 43.876009) (Figure 1), on Sayer date palm trees (7 years old) irrigated by a drip system during the 2024 growing season. For this purpose, 54 trees were selected to be as uniform as possible. The experimental area was divided into three replications, each containing 18 palm trees, with each experimental unit consisting of one tree. The study was set up as a factorial experiment (3 × 3 × 2) using a randomized complete block design (RCBD). Urea was sprayed at a concentration of 0.2% one day before applying the experimental treatments to facilitate the penetration of the applied solutions into the leaflets. Sampling was carried out in August, at the beginning of the rutab (ripening) stage.



Figure 1. The experimental site is located in the desert of Karbala, which is characterized by harsh desert conditions, where temperatures reach up to 55°C, soil salinity (EC) is 5.75 dS/m, well water salinity (EC) is 6.16 dS/m, soil pH is 7.5, and the average annual rainfall is 11 mm.

2.1 Study Factors:

1. **Melatonin** (0, 50, 100 mg/L): the first spray was applied at the kimri stage, the second application should be done 21 days following the initial spray, and the third at the *khalal* stage. Spraying was performed using a hand sprayer until the trees were completely wetted.
2. **Boron** – as boric acid (0, 500 mg/L): the first spray was applied on March 1, the second at the *kimri* stage, and the third at the *khalal* stage.
3. **Algal biofertilizer** (*Chlorella vulgaris*) (0, 100, 200 mL/L): applied to the soil at five dates—10/1, 10/2, 10/3, 10/4, and 10/5—at a rate of 5 liters per tree.

2.2 Studied Traits:

- Total phenols in fruits** (mg/100 g FW) (Wada, L and Boxin, 2002).
- Carotene in fruits** (mg/100 g) (Howrtiz, 1975).
- Fruit ripening percentage (%)** at the rutab stage, determined based on the formula below:
 $Ripening (\%) = (NO. \text{ of ripe fruits} / \text{Total no. of fruits}) \times 100$.
- Phosphorus content (%)**.
- Total yield (kg/palm):** calculated for each palm and each replicate by weighing the fruit bunches immediately after harvesting using a field scale, then calculating the average total yield weight for each treatment individually.

Results and Discussion

3.1 Total phenols in fruits (mg/100 g fresh weight)

The results revealed no significant differences between the boron treatments (Table 1). As for melatonin spray, treatment M2 recorded the highest concentration of total phenols, reaching 190.94 mg/100g FW. Treatment F2 (*Chlorella vulgaris*) yielded 182.06 mg/100g FW. Regarding the interaction between treatments, B1M2F2 and B1M2F1 gave the highest concentration of total phenols, reaching 195.00 mg/100g FW. The increase in phenolic compounds may be attributed to melatonin's ability to alter gene expression and the pathway of gene synthesis and expression, in addition to its capacity to increase the activity of antioxidant enzymes, and this may be a reason for the increase in phenolic compounds (Zhang et al., 2016). The increase with boron compared to untreated palm trees (the control treatment) may be due to the increased concentration of boron in the trees, as the optimal concentration of boron enhances the activity of H⁺-ATPase, thus maintaining electrochemical gradients across the plasma membrane, which enhances boron's ability to bind to cell integrity, increasing its biological effectiveness that causes an increase in phenolic compounds (Shireen et al., 2018; Nejad and Etesami, 2020).

Furthermore, the ability of the unicellular algae (*Chlorella vulgaris*) to provide macro and micronutrients within the soil increases their absorption into the plant, thereby enhancing vitality and food synthesis within the plant (Cakirsoy et al., 2020).

Table 1. Effect of spraying melatonin, boron and adding *Chlorella vulgaris* to the soil on Total phenols in fruits . mg/100 g FW

Total phenols in fruits . mg/100 g FW						
B	M	F			M x B	B average
		F0	F1	F2		
B0	M0	169.00	171.33	172.00	170.78	179.96
	M1	170.33	177.00	187.67	178.33	
	M2	190.67	190.33	191.33	190.78	
B1	M0	165.67	165.33	166.00	165.67	178.96
	M1	174.00	186.00	180.33	180.11	
	M2	183.33	195.00	195.00	191.11	
F average		175.50	180.83	182.06	L.S.D 0.05	L.S.D 0.05
L.S.D 0.05			8.51		M x B	B
					4.3	N.S
F x B	B0	176.67	179.56	183.67	L.S.D 0.05	
	B1	174.33	182.11	180.44	4.3	
F x M	M0	167.33	168.33	169.00	168.22	M average
	M1	172.17	181.5	184.00	179.22	
	M2	87.00	192.67	193.17	190.94	
L.S.D 0.05						
F x M		F			M	
6.36		3.67			3.67	

3.2 Carotenoids in fruits. (mg/100 g FW)

The results revealed no significant differences between B1 and B2 (Table 2). Treatment M2 yielded carotenoids of 0.0956 mg/100g for melatonin spray, and treatment F2 (*Chlorella vulgaris*) yielded 0.0783 mg/100g. As for the interaction between treatments, B1M2F1 gave the highest values for carotenoids at 0.11 mg/100g.

Melatonin's role in enhancing the production of plant pigments is reinforced by its function as an antioxidant, as the appearance of these pigments is due to Melatonin's ability to preserve cell function under stress conditions. Furthermore, Melatonin's ability to enhance the biosynthesis of chromosomes and modify gene expression makes it valuable in improving fruit color development (Back et al., 2016; Sabir et al., 2024). The increase in Boron also increases the level of pigments in the fruits compared to untreated date palms (the control treatment) because it is known that Boron deficiency may cause weakness in the leaf structure, especially young leaves, which causes a malfunction in plant functions, leading to a decrease in the pigment content in the fruits. It was observed that increasing the Boron content causes the accumulation of pigments in the fruit due to Boron's ability to maintain the integrity of the plant cell structure, and the accumulation of pigments was observed (Song et al., 2023). Algae (*Chlorella vulgaris*) are considered rich in beneficial plant pigments such as chlorophyll and carotene, and thus have a clear effect on the carotenoid content in fruits, despite the presence of other factors, algae play an important role in increasing plant pigments (Baweja et al., 2016; Chen et al., 2023).

Table 2. Effect of spraying melatonin, boron and adding *Chlorella vulgaris* to the soil on Carotenoids in fruits. (mg/100 g FW)

Carotenoids in fruits . mg/100 g ⁻¹ FW						
B	M	F			M x B	B average
		F0	F1	F2		
B0	M0	0.0367	0.0467	0.05	0.0444	0.0763
	M1	0.0633	0.0933	0.1033	0.0867	
	M2	0.0933	0.1	0.1	0.0978	
B1	M0	0.0467	0.0533	0.0467	0.0489	0.0774

		M1	0.07	0.1	0.1	0.0900
		M2	0.1	0.11	0.07	0.0933
F average			0.0683	0.0839	0.0783	L.S.D 0.05
L.S.D 0.05				0.03		B x M
B x M x F						0.0155
F x B	B0		0.0644	0.08	0.0844	L.S.D 0.05
	B1		0.0722	0.0878	0.0722	0.0155
F x M	M0		0.0417	0.05	0.0483	0.0467
	M1		0.0667	0.0967	0.1017	0.0883
	M2		0.0967	0.105	0.085	0.0956
L.S.D 0.05						
F x M		F			M	
0.0223		0.0128			0.0128	

3.3 Percentage of fruit maturity%

The results revealed no significant differences were observed among boron treatments B1 and B2 (Table 3). But, treatment M2 achieved the highest fruit ripening percentage (79.17%) in case of melatonin spraying and treatment F1 (*Chlorella vulgaris*) outperformed by registering the highest fruit ripening 77.09%. As for the interaction among treatments, B1M2F2 reported the maximum value of fruit ripening percentage (86.93%).

The increase in Melatonin concentration may contribute to increased gene expression, which improves the rate and quality of fruit ripening, as the Melatonin concentration is believed to be linked to an increase in ethylene concentration, which plays an important role in the ripening of fruits on trees (Ayyaz *et al.*, 2022). An increase in Boron concentration was also observed for the treated trees, as Boron stimulates fruit formation and enhances the integrity of the crucial metabolic process for fruit growth and ripening (Michailidis *et al.*, 2023). Boron is one of the necessary nutrients for the sustainability of this process, although the plant requires it in small quantities. In fact, this element mainly contributes to the transport of carbohydrates to the fruits, which increases their ripening, in addition to its role in the integrity of the cell wall structure and the functions of the cell membranes in fruit cells (Hapuarachchi *et al.*, 2022; Shaymaa *et al.*, 2022).

Table 3. Effect of spraying melatonin, boron and adding *Chlorella vulgaris* to the soil on Percentage of fruit maturity%.

		Percentage of fruit maturity%				
B	M	F			M x B	B average
		F0	F1	F2		
B0	M0	61.33	65.07	70.2	65.53	
	M1	71.43	76.03	80.13	75.87	72.08
	M2	71.6	80.93	72	74.84	
B1	M0	70.03	71.07	72.77	71.29	
	M1	75.93	79.8	80.5	78.74	77.84
	M2	78.33	85.23	86.93	83.5	
F average		71.44	76.36	77.09	L.S.D 0.05	L.S.D 0.05
L.S.D 0.05			5.9		M x B	B
B x M x F					5.48	N.S
F x B	B0	68.12	74.01	74.11	L.S.D 0.05	
	B1	74.77	78.7	80.07	5.48	
F x M	M0	65.68	68.07	71.48	68.41	
	M1	73.68	77.92	80.32	77.31	M average
	M2	74.97	79.47	83.08	79.17	
L.S.D 0.05						
F x M		F			M	
3.28		1.89			1.89	

3.4 Percentage of phosphorus %

Table (4) showed that treatment B1 (Boron spray) gave the highest value of 0.175%, while treatment M2 gave the highest phosphorus percentage of 0.171% for the Melatonin spray. Treatment F1 (*Chlorella vulgaris*) also gave a phosphorus percentage of 0.170%. As for the interaction between treatments, treatment B1M2F2 gave the highest values for the phosphorus percentage of 0.202%.

The relationship between phosphorus and boron is not yet clear, but it was found that the increased absorption and transport of phosphorus is linked to the absorption and transport of boron and vice versa, as well as Boron's ability to maintain the activity of the ATPase enzyme responsible for the hydrogen ion gradient across the cell membrane. The more active this enzyme is, the greater the phosphorus absorption (Ferreira *et al.*, 2021; Paz-Ares *et al.*, 2022). Furthermore, the green algae that feed in the presence of light and high humidity increase their biomass in the soil, leading to an increase in some important elements for the plant through the decomposition of the algae and the dissolution of its content in the nutrient-rich soil, including phosphorus (Çakirsoy *et al.*, 2022 Al-Hassany, and Abbood, 2021; Jabbar, and Hassan, 2020).

Table 4. Effect of spraying melatonin, boron and adding *Chlorella vulgaris* to the soil on Percentage of phosphorus %

B	M	Percentage of phosphorus %				M x B	B average
		F0	F1	F2			
B0	M0	0.122	0.138	0.142	0.134	0.14	
	M1	0.121	0.126	0.152	0.133		
	M2	0.123	0.163	0.176	0.154		
B1	M0	0.126	0.166	0.169	0.153	0.175	
	M1	0.175	0.189	0.181	0.182		
	M2	0.176	0.188	0.202	0.188		
F average		0.14	0.161	0.170	L.S.D 0.05	L.S.D 0.05	
L.S.D 0.05			0.021		M x B	B	
B x M x F					0.016	0.021	
F x B	B0	0.122	0.142	0.157	L.S.D 0.05	0.016	
	B1	0.159	0.181	0.184			
F x M	M0	0.124	0.152	0.155	0.144	M average	
	M1	0.148	0.157	0.167	0.157		
	M2	0.149	0.175	0.189	0.171		
L.S.D 0.05							
F x M		F			M		
0.014		0.008			0.008		

3.5 Total yield (kg/palm)

The results revealed that treatment B1 gave the highest total yield, reaching 24.32 kg/date palm (Table 5), while treatment M2 gave the highest total yield, reaching 23.16 kg/date palm for the Melatonin spray. Treatment F2 (*Chlorella vulgaris*) gave the highest total yield, reaching 23.87 kg/date palm. As for the interaction between treatments, treatment B1M2F2 recorded the highest values for total yield (26.97 kg/date palm). The important role of Boron in the transport of food from its source (the tree leaves) to its final location (the fruits) increases the fruit size and improves their quality due to its vital role in cell integrity (Sayed et al., 2024; Abd El-Wahed et al., 2024). Also, Melatonin and its important role in reducing biological stresses and its ability to accelerate fruit ripening increase their size and help increase some phenolic compounds in them, leading to the production of healthy and high-quality fruits (Cano et al., 2024). As for the role of algae, its abundance in the soil and increased biomass enhance soil fertility and increase its content of nutrients important for plant growth. The accumulation of these factors will lead to an increase in the total yield (Shaddad et al., 2024; Saleem et al., 2019).

Table 5. Effect of spraying melatonin, boron and adding *Chlorella vulgaris* to the soil on Total yield. Kg/palm

B	M	Total yield .kg palm ⁻¹				M x B	B average
		F0	F1	F2			
B0	M0	17.43	18.17	20.3	18.63	20.1	
	M1	18.6	20.73	21.8	20.38		
	M2	20.03	21.7	22.17	21.3		
B1	M0	21.7	22.57	24.7	22.99	24.32	
	M1	23.27	24.3	27.3	24.96		
	M2	23.63	24.43	26.97	25.01		
F average		20.78	21.98	23.87	L.S.D 0.05	L.S.D 0.05	
L.S.D 0.05			1.522		M x B	B	
B x M x F					0.787	0.497	
F x B	B0	18.69	20.2	21.42	L.S.D 0.05	0.787	
	B1	22.87	23.77	26.32			
F x M	M0	19.57	20.37	22.5	20.81	M average	
	M1	20.93	22.52	24.55	22.67		
	M2	21.83	23.07	24.57	23.16		
L.S.D 0.05							
F x M		F			M		
1.129		0.652			0.652		

Conclusion

Spraying melatonin and boron on palm trees shows an important relationship between them that requires other studies, as spraying them together led to the growth and production of palm trees and improved the chemical and qualitative characteristics of the fruits under environmental stress conditions. The use of (*Chlorella vulgaris*) algae as a biofertilizer also contributed to increasing soil fertility and increasing its content of nutrients, as a form of sustainable agriculture that maintains the soil from pollutants, increasing the total yield.

Acknowledgment

The authors express their sincere gratitude to the College of Agricultural Engineering Sciences, University of Baghdad, for providing the research facilities and support needed to complete this study. Appreciation is also extended to the staff of the Fadak Date Palm Farm in Karbala for their valuable assistance during fieldwork and data collection.

Authors' Contribution

Mustafa E. Al-Asally designed and conducted the experiment, collected the data, and wrote the first draft of the manuscript. **Salah H. J. Al-Hchami** supervised the study, contributed to data analysis, interpretation, and manuscript revision. Both authors reviewed and approved the final version of the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Novelty Statement

This research presents the first integrated study evaluating the combined effects of melatonin, boron, and *Chlorella vulgaris* algae on the physiological, biochemical, and yield characteristics of *Phoenix dactylifera* cv. Al-Sayer under desert stress conditions. The results demonstrate that applying these bioactive agents together can significantly enhance fruit quality, nutrient absorption, and overall yield in date palms, offering a sustainable strategy for improving production under harsh environmental conditions.

References

- Abd El-Wahed, A.E.W.N., S.M. Khalifa, M.D. Alqahtani, A.M. Abd-Alrazik, H. Abdel-Aziz, A. Mancy, I.A. Elnaggar, B.M. Alharbi, A. Hamdy and A. Elkelish, 2024. Nano-enhanced growth and resilience strategies for pomegranate Cv. Wonderful: unveiling the impact of zinc and boron nanoparticles on fruit quality and abiotic stress management. *J. Agric. Food Res.*, 15:100908.
- Abinandan, S., S.R. Subashchandrabose, K. Venkateswarlu and M. Megharaj, 2019. Soil microalgae and cyanobacteria: the biotechnological potential in the maintenance of soil fertility and health. *Crit. Rev. Biotechnol.*, 39(8):981–998.
- Al-Bekr, A.J., 1972. The date palm: a review of its past, present status and the recent advances in its culture industry and trade. Iraq, 1085 pp.
- Al-Hassany, H.A. and M.R. Abbood, 2021. Effect of boron spray and pollination methods on “Zahdi” date palm yield and fruit quality. *Ann. Rom. Soc. Cell Biol.*, 25(6):10203–10208.
- Al-Naqeeb, M.A., I.H.H. Al-Hilfy, W.F. Humood and H.M.K. Al-Abodi, 2010. Effect of zinc and boron on growth and yield of cotton. *Iraqi J. Agric. Sci.*, 41(6):11–20.
- Arnao, M.B. and J. Hernández-Ruiz, 2021. Melatonin as a regulatory hub of plant hormone levels and action in stress situations. *Plant Biol.*, 23:7–19.
- Ayyaz, A., A.K. Shahzadi, S. Fatima, G. Yasin, Z.U. Zafar, H.U.R. Athar and M.A. Farooq, 2022. Uncovering the role of melatonin in plant stress tolerance. *Theor. Exp. Plant Physiol.*, 34(3):335–346.
- Back, K., D.X. Tan and R.J. Reiter, 2016. Melatonin biosynthesis in plants: multiple pathways catalyze tryptophan to melatonin in the cytoplasm or chloroplasts. *J. Pineal Res.*, 61(4):426–437.
- Baweja, P., S. Kumar, D. Sahoo and I. Levine, 2016. Biology of seaweeds: seaweed in health and disease prevention. Academic Press, pp. 41–106.
- Çakırsöy, I., T. Miyamoto and N. Ohtake, 2022. Physiology of microalgae and their application to sustainable agriculture: a mini-review. *Front. Plant Sci.*, 13:1005991.
- Cano, A., J. Hernández-Ruiz and M.B. Arnao, 2024. Role of exogenous melatonin in plant biotechnology: physiological and applied aspects. *Crit. Rev. Plant Sci.*, 43(6):395–404.
- Chen, Z., W. Wu, Y. Wen, L. Zhang, Y. Wu, M.S. Farid, X. Zhao, X. Wang, C. Zhang and C. Zhao, 2023. Recent advances of natural pigments from algae. *Food Prod. Process. Nutr.*, 5(1):39.
- Ferreira, G.A., F.W. Hippler, L.A.D.S. Prado, J.A. Rima, R.M. Boaretto, J.A. Quaggio, A.R. Façanha and D. Mattos Jr, 2021. Boron modulates the plasma membrane H⁺-ATPase activity affecting nutrient uptake of citrus trees. *Ann. Appl. Biol.*, 178(2):293–303.
- Hapuarachchi, N.S., W. Kämper, H.M. Wallace, S. Hosseini Bai, S.M. Ogbourne, J. Nichols and S.J. Trueman, 2022. Boron effects on fruit set, yield, quality and paternity of Hass avocado. *Agronomy*, 12(6):1479.
- Howrtiz, W., 1975. Official methods of analysis. Association of Official Analytical Chemists, Washington D.C., U.S.A.
- Jabbar, S.H. and Z.A. Hassan, 2020. Effect of spraying date of gibberellic acid and boron on some physical characteristics of palm trees cv. Khadhrawi. *Plant Arch.*, 20(1).
- Michailidis, M., C. Bazakos, M. Kollaros, I.D.S. Adamakis, I. Ganopoulos, A. Molassiotis and G. Tanou, 2023. Boron stimulates fruit formation and reprograms developmental metabolism in sweet cherry. *Physiol. Plant.*, 175(3):e13946.
- Mitter, E.K., M. Tosi, D. Obregón, K.E. Dunfield and J.J. Germida, 2021. Rethinking crop nutrition in times of modern microbiology: innovative biofertilizer technologies. *Front. Sustain. Food Syst.*, 5:606815.
- Nejad, S.A.G. and H. Etesami, 2020. The importance of boron in plant nutrition. *Metalloids in Plants: Advances and Future Prospects*, 433–449.
- Paz-Ares, J., M.I. Puga, M. Rojas-Triana, I. Martínez-Hevia, S. Diaz, C. Poza-Carrión, M. Miñambres and A. Leyva, 2022. Plant adaptation to low phosphorus availability: core signaling, crosstalks, and applied implications. *Mol. Plant.*, 15(1):104–124.
- Pereira, G.L., J.A. Siqueira, W. Batista-Silva, F.B. Cardoso, A. Nunes-Nesi and W.L. Araújo, 2021. Boron: more than an essential element for land plants. *Front. Plant Sci.*, 11:610307.
- Sabir, I.A., M.A. Manzoor, I.H. Shah, K. Shah, W. Ahmed, X. Hu, F. Wang, Y. Zhao, H. Li, Q. Liu and Y. Qin, 2024. Melatonin's chromatic magic: examining its role in orchestrating pigment biosynthesis in horticultural crops. *Sci. Hortic.*, 323:112482.
- Sadiq, S.M., 2023. Effect of foliar spraying with boron and brassinolide on the growth and flowering of gladiolus. *IOP Conf. Ser.: Earth Environ. Sci.*, 1259(1):012060.
- Saleem, Q.T.S. and A.T. Joody, 2019. Effect of silicon, calcium and boron on apple leaf minerals content. *Iraqi J. Agric. Sci.*, 50(1):296–301.
- Sayed, H.F. and A.M. Gomma, 2024. Evaluating the impact of spraying nano potassium and nano boron on productivity and fruit quality of Medjool date palm. *J. Plant Prod.*, 15(7):373–378.
- Shaddad, A., F.E. Fahmy and S.A. Farid, 2024. Improving productivity and fruit quality in Murcott mandarin trees by foliar application of chelate zinc and algae *Amphora coffeaeformis* under New Valley conditions. *Egypt. J. Hortic.*, 51(2):279–294.
- Shaker, U. and I.A. Rasool, 2023. Effect of organic fertilizer and boron foliar on quantitative and qualitative traits of potato for processing. *Iraqi J. Agric. Sci.*, 54(6).
- Shaymaa, M.A., Z.R. Ibrahim and H.S. Nabi, 2022. Response of almond seedlings (*Prunus amygdalus*) to spray of aminoplasmal, humic acid and boron. *Iraqi J. Agric. Sci.*, 53(2):415–428.
- Shireen, F., M.A. Nawaz, C. Chen, Q. Zhang, Z. Zheng, H. Sohail, J. Sun, H. Cao, Y. Huang and Z. Bie, 2018. Boron: functions and approaches to enhance its availability in plants for sustainable agriculture. *Int. J. Mol. Sci.*, 19(7):1856.
- Song, X., B. Song, J. Huo, H. Liu, M.F. Adil, Q. Jia, X. Wang, Y. Zhang, L. Chen and W. Huang, 2023. Effect of boron deficiency on the photosynthetic performance of sugar beet cultivars with contrasting boron efficiencies. *Front. Plant Sci.*, 13:1101171.
- Wada, L. and B. Ou, 2002. Antioxidant activity and phenolic content of Oregon caneberries. *J. Agric. Food Chem.*, 50:3495–3500.
- Zeng, W., S. Mostafa, Z. Lu and B. Jin, 2022. Melatonin-mediated abiotic stress tolerance in plants. *Front. Plant Sci.*, 13:847175.
- Zhang, N., Q.Q. Sun, H.F. Li, X.S. Li, Y.Y. Cao, H.J. Zhang, H. Wei, L. Ding, Y. Tang, X. Zhao and X. Zhang, 2016. Melatonin improved anthocyanin accumulation by regulating gene expressions and resulted in high reactive oxygen species scavenging capacity in cabbage. *Front. Plant Sci.*, 7:197.