Egypt. J. Soil Sci. **Vol. 64**, No. 4, pp: 1585- 1599 (2024)

Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Organic Fertilization and Melatonin: Improving Crisphead Lettuce Performance in Water-Limited Conditions

Amal A. Helmy[1], Mohamed A. El-Sherpiny[2] and **Dina A. Ghazi[1]**

[1] *Soils Dept. Fac. Agric., Mansoura University, Mansoura, 35516, Egypt*
[2] *Soil & Water and Environment Research Institute, Agriculture Research Center, Giza, 12619 Egypt*

WATER scarcity in Egypt presents significant challenges to agriculture, necessitating the development of innovative strategies to enhance vegetable crops resilience and productivity under limited water conditions. This study investigates the effects of organic fertilization and melatonin application on the performance of crisphead lettuce (*Lactuca sativa* L.) under water stress conditions. The experiment was conducted over two growing seasons (2022 and 2023) at the research farm of the Faculty of Agriculture, Mansoura University, Egypt and evaluated the impact of three irrigation regimes as a main factor (100%, 80%, and 60% of evapotranspiration, ET_O) combined with different organic fertilization treatments as a sub-main factor (without, plant compost, chicken manure compost and vermicompost) and foliar application of melatonin as a sub-sub main factor (0.0 and 70 mmol L^{-1}). Results indicated that reducing irrigation levels significantly increased enzymatic antioxidant activities, including superoxide dismutase, peroxidase, and catalase. Organic fertilization, particularly with plant compost, improved leaf chemical constituents and photosynthetic pigments, while melatonin application further enhanced these traits. Growth performance metrics, such as fresh and dry weight, leaf area, and relative water content, showed significant improvements with combined treatments of organic fertilizers and melatonin under water-limited conditions. For example, in the first season, the maximum head weight of 1124.38 g was achieved with full irrigation (100% ET_O). However, reducing the irrigation level to 80% and 60% resulted in lower head weights of 955.67 g and 653.67 g, respectively. Among the organic fertilization treatments, plant compost produced the highest head weight at 972.56 g, while the control treatment had the lowest at 770.50 g. Additionally, foliar application of melatonin increased the head weight to 931.94 g, compared to 890.53 g in the control treatment. This study highlights the potential of integrated organic and hormonal treatments to mitigate the adverse effects of water stress on lettuce production. Future research should focus on refining these strategies and exploring their applicability to other crops to further address the challenges posed by water scarcity in arid regions like Egypt.

Keywords: Water scarcity, Arid regions, Antioxidant activity, Compost, Melatonin.

Introduction

Water scarcity is a pressing issue in Egypt, posing a significant threat to its agricultural sector. The country's limited freshwater resources are under increasing pressure due to population growth, urbanization, and climate change, making it crucial to develop innovative strategies to enhance the resilience and productivity of vegetable crops under water-limited conditions (**Doklega *et al.* 2023)**. Addressing this challenge is vital for ensuring food security and sustainable agricultural practices in the region (**Elsherpiny and Helmy, 2022).** Water deficiency has significant negative effects on plant growth and productivity. When plants are exposed to water stress, photosynthesis rates decrease, and the ability of roots to absorb nutrients from the soil is reduced, negatively affecting the development of vegetative parts and fruiting. Additionally, water deficiency disrupts the balance of plant hormones, leading to a reduction in crop size and weight, which in turn deteriorates its quality **(Ghazi *et al.* 2023)**.

One promising approach to mitigating the adverse effects of water stress is the use of organic fertilization. Organic fertilizers can improve soil health, enhance water retention, and supply essential nutrients, which are critical for plant growth and development under drought conditions. Among various organic fertilizers, plant compost, chicken manure compost (ChM compost), and vermicompost have gained attention for their beneficial effects on soil

*Corresponding author e-mail: m_elsherpiny2010@yahoo.com
Received: 13/08/2024; Accepted: 15/09/2024
DOI: 10.21608/EJSS.2024.312298.1843

and plant health (**Kareem and Hamed 2024)**. Plant compost is composed of decomposed organic matter, primarily derived from plant residues. It enhances soil structure, increases nutrient availability, and improves water-holding capacity, making it an excellent amendment for supporting plant growth under water stress (**Elsherpiny, 2023)**. Chicken manure compost (ChM compost) is produced by the decomposition of chicken manure. It is rich in nutrients and organic matter, providing a steady supply of essential elements that can boost plant growth and improve soil fertility. ChM compost has been shown to enhance microbial activity in the soil, leading to better nutrient cycling and increased resilience of plants to environmental stresses (**Abumere *et al*. 2019)**. Vermicompost, produced through the breakdown of organic waste by earthworms, is another effective organic amendment. It is rich in beneficial microorganisms, enzymes, and plant growth-promoting hormones, which can enhance nutrient uptake, improve root growth, and increase plant tolerance to abiotic stress factors, including drought **(Elsaied *et al.* 2024).**

In addition to organic fertilization, the application of melatonin has emerged as a promising strategy to enhance plant resilience to water scarcity (**Sadak *et al.* 2020)**. Melatonin is a naturally occurring hormone in plants, known for its role in regulating growth, development, and stress responses. It acts as an antioxidant, protecting plants from oxidative damage caused by drought stress, and has been reported to improve photosynthetic efficiency, enhance root growth, and increase water-use efficiency **(Elsherpiny *et al*. 2024**; **Elsaied *et al.* 2024).** Crisphead lettuce (*Lactuca sativa* L.), commonly known as iceberg lettuce, is a popular leafy vegetable sensitive to water stress. Under limited water conditions, lettuce exhibits reduced growth, lower leaf quality, and decreased yield, impacting both productivity and marketability. Therefore, identifying effective strategies to improve lettuce performance under water stress is essential (**Mostafa *et al.* 2023; Elsherpiny *et al*. 2024)**.

The major aim of the current study is to evaluate the effects of organic fertilization and melatonin application on the growth, physiological responses, and productivity of crisphead lettuce under varying irrigation regimes. By exploring the synergistic effects of these treatments, this research aims to develop practical solutions for enhancing lettuce resilience and productivity under water-limited conditions, contributing to sustainable agriculture in arid regions like Egypt.

2. Material and Methods

The study was conducted at the research farm of the Faculty of Agriculture, Mansoura University, Egypt. The experimental design employed was a split-split plot with three replicates. The experiment was conducted over two growing seasons (2022 and 2023) to evaluate the impact of three irrigation regimes as a main factor (100%, 80% and 60% of evapotranspiration, ET_O) combined with different organic fertilization treatments as a sub-main factor [without organic fertilization, plant compost (sourced from banana tree residues), chicken manure compost and vermicompost) and foliar application of melatonin as a sub-sub main factor (0.0 and 70 mmol L^{-1}). Each sub-sub plot had an area of 9.0 m² (3.0 m x 3.0 m), and contains 6 planting lines. The distance between the irrigation treatments was 3 meters, separating each treatment from the others. The flowchart of the experiment is illustrated in Fig 1.

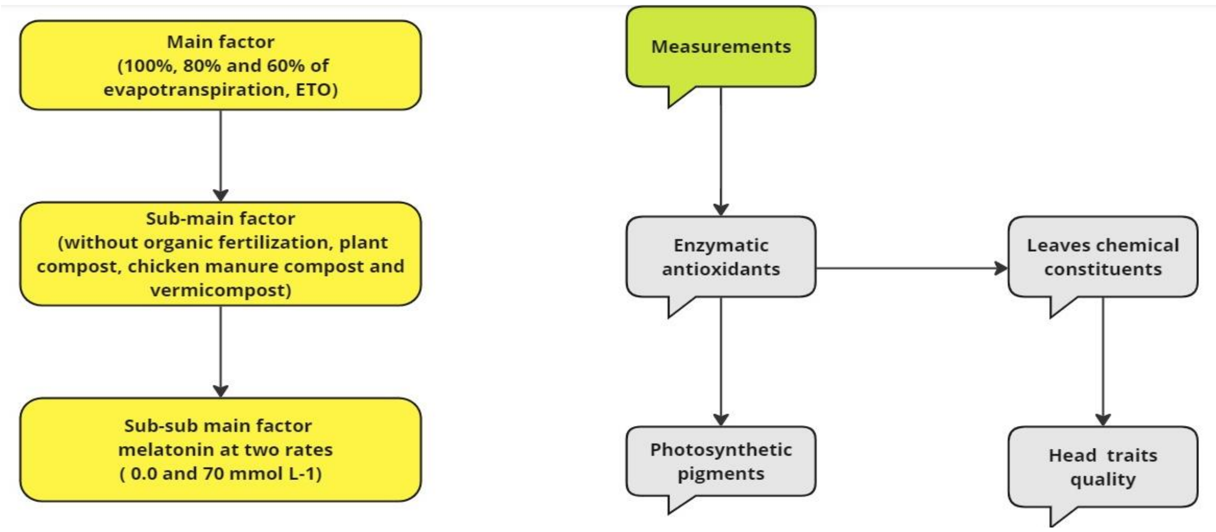

Fig. 1. The flowchart of the experiment.

Before the experiment, initial soil properties were analyzed to determine baseline conditions. The soil was characterized for parameters such as texture, pH, organic matter content, and nutrient levels. Also, the studied composts were analyzed to identify their properties. Both initial soil and compost were analyzed according to the standard methods following **Tandon's (2005)** guidelines (Table1). Transplanting was carried out at the appropriate growth stage of crisphead lettuce seedlings. Crisphead lettuce seedlings (*Lactuca sativa* L. cv Kharga), aged 30 days, were transplanted on October 10th in both seasons. Transplanting was carried out in the center of the ridges, maintaining a plant spacing of 45 cm. Prior to plowing, all plots received calcium superphosphate (6.6% P) at a rate of 72 units P ha^{-1}. Nitrogen fertilization was administered in two equal doses. The first dose was applied two weeks after transplanting, followed by the second dose two weeks later, using urea (46% N) at a rate of 120 units N ha^{-1}. Potassium sulfate, containing 48% K_2O, was applied simultaneously with the nitrogen, at a rate of 60 units K_2O ha^{-1}. The irrigation treatments were calculated based on evapotranspiration (ET_O) rates. To estimate evapotranspiration in this study, evaporation pans were utilized. This method involves measuring the amount of water evaporated from a standardized pan over a specific period, which is then used to calculate the evapotranspiration rate.

Table 1. Properties of the initial soil and studied organic fertilizers (Data is the combined data over both studied seasons) using the stander methods as described by Tandon (2005).

Property	Initial soil	Organic fertilizers		
		Plant compost	ChM compost	Vermicompost
pH	8.2 (suspension 1:2.5)	6.28	6.14	6.16
		(suspension 1:10)		
EC, dSm^{-1}	2.95	4.00	4.60	4.25
Total C, %	/	18.2	17.8	18.0
Total N, %	/	1.50	1.35	1.44
Total P, %	/	1.60	1.15	1.35
Total K, %	/	1.45	1.08	1.26
C:N ratio	/	12.13	13.2	12.5
Available N, mgKg^{-1}	29.9	/	/	/
Available P , mg kg^{-1}	7.89	/	/	/
Available K, mg kg^{-1}	208	/	/	/
Mn, mg kg^{-1}	1.66	98.0	75.2	88.5
Zn, mg kg^{-1}	1.45	24.5	19.6	21.0
Organic matter, %	1.33	31.4	30.7	31.0
Sand	18.0	/	/	/
Clay	49.5	/	/	/
Silt	32.5	/	/	/
Textural	Clayey	/	/	/

The study included three irrigation regimes: 100%, 80%, and 60% of ET_O. Water application was adjusted to match these regimes throughout the growing season. Organic fertilizers were applied two months before transplanting according to the studied treatments at a rate of 10 ton ha^{-1} for each organic fertilizer under study. Foliar application of melatonin was performed three times: on days 30, 40, and 50 post-transplant according to the studied treatments. Melatonin was applied at a concentration of 70 mmol L^{-1}. At 70 days post-transplant, three crisphead lettuce plants were randomly sampled from each replicate to measured and determined performance traits and yield attributes (Table 2).

Statistical analysis of the data was performed using the methodology outlined by **Gomez and Gomez (1984)** with CoStat version 6.303 (1998-2004). Treatment means were compared using the least significant difference (LSD) at a significance level of 0.05 probability.

Table 2. Measurements during the studied stages.

Parameters	Methods	Refs.
Enzymatic antioxidants in fresh leaves		
Superoxide dismutase, unit mg^{-1} $protein^{-1}$ Peroxidase, unit mg^{-1} $protein^{-1}$ Catalase, unit mg^{-1} $protein^{-1}$	Spectrophotometrically	**[1]**
Leaves chemical constituents and photosynthetic pigments		
Leaves digestion	Using a mixture of $HClO_4$ + H_2SO_4	**[2]**
Leaf chemical NPK (% DW)	Micro-Kjeldahl (for N) Spectrophotometric (for P) Flame photometer (for K)	**[3]**
Chlorophyll	SPAD meter (SPAD-502, Minolta Camera, Osaka, Japan)	**[4]**
Carotene (mg g^{-1} FW)	Spectrophotometrically, using acetone	**[5]**
Growth criteria and head traits		
Fresh and dry weights (g $plant^{-1}$), leaf area (cm^2 $plant^{-1}$), relative water content (%) head weight (g), head diameter (cm), head height (cm), and the number of outer leaves	Manually, visually and Mathematically	----------
Head quality parameters		
Total carbohydrates percentage	Anthrone method	**[6]**
Protein percentage	Micro-kjeldahl	**[6]**
Total sugar, %	Sulfuric acid and phenol	**[6]**
Fiber	Sulfuric acid and sodium hydroxide	**[6]**
Total dissolved solids, %	Hand refractometer	**[6]**
Dry mater, %	Using the oven	**[7]**
Vitamin C, mg 100 g^{-1} (F.W)	Spectrophotometrically using potassium permanganates	**[8]**
Vitamin E, mg 100 g^{-1} (F.W)	Spectrophotometrically	**[8]**

List of refs: **[1]** Elavarthi and Martin, (2010), [**2**] Peterburgski (1968), **[3]** Walinga *et al.* (2013), **[4]** Uddling *et al.* (2007), **[5]** Dere (1998), **[6**] A.O.A.C (2000), **[7]** Garnier *et al.* (2001), **[8]** Saeed *et al.* (2018)

3. Results

3.1 Enzymatic antioxidants

Data in Table 3 illustrate the effects of different irrigation regimes, organic fertilizers and melatonin application on enzymatic antioxidant activities, specifically superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) in crisphead lettuce leaves. As expected, water stress represented by reduced irrigation levels (80% and 60% of ET_O), led to a significant increase in the activity of these enzymes compared to the full irrigation treatment (100% ET_O). This suggests that the plants activated their antioxidant defense systems in response to drought stress to mitigate oxidative damage. Organic fertilization significantly impacted enzymatic activities, with plant compost and vermicompost treatments showing the highest decreases in SOD, POD, and CAT activities under water stress conditions (80% and 60% of ET_O) compared to the full irrigation treatment (100% ET_O). This indicates the potential of organic amendments to enhance the plant's stress tolerance by bolstering its antioxidant capacity. The application of melatonin further decreased the enzymatic antioxidant activities across all irrigation and fertilization treatments, highlighting melatonin's role as a protective agent against oxidative stress. Under water deficit treatments (80% and 60% of ET_O), the addition of any organic fertilizer in conjunction with spraying melatonin led to decrease the values of SOD, POD, and CAT compared to the values of plants grown under control groups.

Table 3. Impact of different irrigation regimes, along with different organic fertilization treatments and spraying melatonin on leaves enzymatic performance of crisphead lettuce during seasons of 2022and 2023.

Treatments			Super oxidase dismutase, unit mg^{-1} protein^{-1}		Peroxidase, unit mg^{-1} protein^{-1}		Catalase, unit mg^{-1} protein^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation treatments								
I_1: 100% of ET_O			179.07c	181.13c	0.327c	0.333c	29.82c	30.16c
I_2: 80% of ET_O			242.24b	245.24b	0.636b	0.647b	43.56b	44.08b
I_3: 60% of ET_O			306.24a	309.78a	0.924a	0.942a	57.26a	58.18a
Organic fertilization treatments								
C_0: Control (without)			262.96a	266.30a	0.727a	0.743a	48.65a	49.40a
C_1: Plant compost (10 ton ha^{-1})			229.06d	231.94d	0.563d	0.573d	40.25d	40.79d
C_2: ChM compost (10 ton ha^{-1})			235.93c	238.49b	0.597b	0.608c	41.75c	42.40c
C_3: Vermicompost (10 ton ha^{-1})			242.11b	244.80c	0.629c	0.638b	43.54b	43.96b
Foliar application treatments								
F_0: Control (without)			250.89a	253.98a	0.670a	0.683a	45.57a	46.17a
F_1: Melatonin (70 mmol L^{-1})			234.14b	236.78b	0.588b	0.599b	41.53b	42.11b
Interaction								
I_1	**C_0**	**F_0**	204.97	207.50	0.460	0.470	35.59	36.08
		F_1	196.20	198.24	0.418	0.426	33.74	34.13
	C_1	**F_0**	170.10	171.80	0.281	0.287	28.65	28.91
		F_1	164.03	165.84	0.233	0.237	25.02	25.31
	C_2	**F_0**	177.71	180.07	0.331	0.338	30.47	30.85
		F_1	165.00	166.59	0.245	0.249	25.41	25.76
	C_3	**F_0**	186.29	188.93	0.379	0.385	32.10	32.35
		F_1	168.24	170.07	0.268	0.272	27.60	27.90
I_2	**C_0**	**F_0**	272.34	276.65	0.773	0.789	49.64	50.14
		F_1	264.05	267.81	0.735	0.750	48.58	48.61
	C_1	**F_0**	238.04	241.72	0.614	0.626	42.55	43.26
		F_1	212.90	215.46	0.503	0.513	37.39	37.83
	C_2	**F_0**	246.07	248.51	0.659	0.666	44.45	44.83
		F_1	220.83	223.40	0.537	0.548	38.84	39.45
	C_3	**F_0**	254.44	256.92	0.691	0.704	46.41	47.06
		F_1	229.24	231.41	0.574	0.585	40.61	41.44
I_3	**C_0**	**F_0**	320.71	324.49	0.995	1.025	62.49	63.94
		F_1	319.48	323.10	0.979	0.999	61.84	63.51
	C_1	**F_0**	307.50	311.91	0.934	0.952	56.49	57.37
		F_1	281.78	284.91	0.814	0.826	51.41	52.09
	C_2	**F_0**	315.98	319.05	0.954	0.973	58.27	59.73
		F_1	289.97	293.33	0.855	0.873	53.02	53.76
	C_3	**F_0**	316.46	320.26	0.968	0.978	59.68	59.49
		F_1	298.00	301.22	0.892	0.907	54.84	55.52
LSD $_{at\ 5\%}$			**1.67**	**4.11**	**0.012**	**0.009**	**0.50**	**0.99**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

3.2 Leaves chemical constituents and photosynthetic pigments

Table 4 presents the impact of different irrigation regimes, organic fertilization treatments and melatonin application on the leaf chemical constituents and photosynthetic pigments of crisphead lettuce over two growing seasons (2022 and 2023). The results highlight how these factors influence nitrogen (N), phosphorus (P), potassium (K), chlorophyll (measured as SPAD reading) and carotene contents. The nutrient contents (N, P and K) were highest under full irrigation (100% ET_O) and decreased with increasing water stress. The lowest values of NPK contents were recorded under the 60% ET_O treatment, indicating a reduction in nutrient uptake and assimilation under drought conditions. This trend underscores the necessity of sufficient water supply for optimal nutrient uptake in lettuce plants. Chlorophyll content, as indicated by SPAD readings, and carotene levels were significantly higher at 100% ET_O compared to lower irrigation levels. This decrease in pigment content under water stress reflects a decline in photosynthetic efficiency and leaf quality due to reduced water availability.

Among the organic fertilizers, plant compost treatment consistently resulted in the highest nutrient content across both seasons, followed by ChM compost and then vermicompost and lately control treatment. This suggests that plant compost may be more effective in enhancing nutrient availability and uptake compared to other organic amendments. Similarly, plant compost led to the highest chlorophyll and carotene content, enhancing photosynthetic pigments and potentially improving photosynthesis and plant vigor. This indicates that organic fertilizers can mitigate some of the negative effects of water stress by enhancing soil nutrient status and plant nutrient uptake. Melatonin-treated plants exhibited significantly higher nutrient content, chlorophyll, and carotene values compared to untreated controls. This enhancement suggests that melatonin may play a crucial role in protecting photosynthetic apparatus and enhancing nutrient assimilation under stress conditions, likely due to its antioxidant properties and ability to improve plant stress responses.

The interaction between irrigation levels, organic fertilizers and melatonin applications reveals that the highest nutrient and pigment contents were recorded under the combination of full irrigation with plant compost and melatonin application. Even under reduced irrigation levels, the combination of organic fertilization and melatonin substantially improved plant nutrient and pigment levels, underscoring the synergistic benefits of these treatments. Overall, these findings highlight the potential of integrating organic fertilization and melatonin application to improve nutrient status and photosynthetic pigment content in crisphead lettuce under varying irrigation conditions, providing a strategy to enhance lettuce resilience and productivity under water stress.

3.3 Growth criteria and head physical traits

Tables 5 and 6 show the effect of the studied treatments on the growth performance of crisphead lettuce, including parameters such as fresh and dry weight, leaf area, and head physical traits [head weight **(Fig 2),** diameter and height as well as No. of outer leaves]. As anticipated, reduced irrigation levels negatively affected growth metrics and head traits, with plants under 60% ET_O showing the most significant declines in biomass and leaf area. This impact underscores the importance of adequate water supply for optimal lettuce growth. In other words, $\mathbf{I_1}$ treatment (100% of ET_O) consistently yielded the highest values across all growth parameters and head physical traits being significantly greater than other irrigation treatments. This suggests that full irrigation is optimal for lettuce growth, providing sufficient moisture for maximum biomass production and leaf area expansion. The relative water content was also the highest under this treatment, indicating better water status and turgidity in the plants**.** $\mathbf{I_2}$ treatment (80% of ET_O) showed a moderate reduction in these parameters compared to $\mathbf{I_1}$ treatment. Fresh weight and dry weight were slightly lower, and leaf area and relative water content, head weight, diameter and height as well as No. of outer leaves were also reduced. This implies that reducing water to 80% of ET_O begins to stress the plants, affecting their growth and water retention abilities, but not as severely as more restricted irrigation. $\mathbf{I_3}$ treatment (60% of ET_O) resulted in the lowest growth performance and head physical traits, with significant reductions in fresh weight, dry weight, leaf area, and relative water content, head weight, diameter and height as well as No. of outer leaves. This indicates that severe water deficit conditions greatly inhibit lettuce growth, likely due to insufficient water availability for cellular processes and expansion. Organic fertilization, particularly with plant compost and ChM compost, substantially improved growth criteria and head traits even under water-limited conditions. These treatments likely enhanced soil fertility and moisture retention, supporting better plant growth. Generally, the superior organic treatment was plant compost followed by ChM compost then vermicompost and lately control group. Melatonin application further boosted growth parameters and head physical traits, suggesting its role in promoting cell division, elongation, and overall biomass accumulation.

Table 4. Impact of different irrigation regimes, along with different organic fertilization treatments and spraying melatonin on leaves chemical constituents and photosynthetic pigments of crisphead lettuce during seasons of 2022and 2023.

Treatments			N, %		P, %		K, %		Chlorophyll, SPAD reading		Carotene, mg g^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation treatments												
I$_1$: 100% of ET$_O$			3.63a	3.70a	0.457a	0.465a	3.41a	3.47a	48.20a	48.88a	0.398	0.405a
I$_2$: 80% of ET$_O$			3.25b	3.31b	0.407b	0.414b	3.06b	3.12b	46.42b	47.17b	0.351a	0.358b
I$_3$: 60% of ET$_O$			2.43c	2.48c	0.308c	0.314c	2.37c	2.42c	42.13c	42.79c	0.241b	0.245c
Organic fertilization treatments												
C$_0$: Control			2.70d	2.76d	0.341d	0.348a	2.59d	2.63d	43.74c	44.33c	0.279d	0.284d
C$_1$: Plant compost			3.32a	3.39c	0.416c	0.424c	3.14a	3.20a	46.69a	47.36a	0.357a	0.363a
C$_2$: ChM compost			3.23b	3.29b	0.408b	0.415b	3.06b	3.12b	46.09b	46.83ab	0.347b	0.353b
C$_3$: Vermicompost			3.16c	3.22a	0.398a	0.405a	3.01c	3.06c	45.81b	46.59b	0.337c	0.343c
Foliar application treatments												
F$_0$: Control			3.01b	3.07b	0.380b	0.387b	2.87b	2.92b	45.05b	45.73b	0.317b	0.323b
F$_1$: Melatonin (70			3.20a	3.26a	0.402a	0.408a	3.03a	3.08a	46.12a	46.83a	0.342a	0.349a
Interaction												
I$_1$	**C$_0$**	**F$_0$**	2.97	3.03	0.375	0.383	2.79	2.84	45.62	46.07	0.316	0.322
		F$_1$	3.04	3.11	0.387	0.394	2.88	2.93	45.58	46.14	0.330	0.337
	C$_1$	**F$_0$**	3.85	3.92	0.485	0.495	3.61	3.69	49.01	49.74	0.423	0.431
		F$_1$	3.95	4.04	0.496	0.502	3.70	3.77	49.90	50.54	0.436	0.446
	C$_2$	**F$_0$**	3.76	3.82	0.474	0.482	3.53	3.59	48.11	48.88	0.414	0.422
		F$_1$	3.91	4.00	0.490	0.499	3.67	3.73	49.73	50.52	0.434	0.443
	C$_3$	**F$_0$**	3.68	3.75	0.461	0.470	3.45	3.51	48.09	48.76	0.403	0.407
		F$_1$	3.88	3.95	0.488	0.498	3.64	3.70	49.55	50.36	0.428	0.435
I$_2$	**C$_0$**	**F$_0$**	2.78	2.84	0.352	0.359	2.65	2.69	44.42	44.97	0.292	0.298
		F$_1$	2.88	2.95	0.362	0.369	2.72	2.78	44.87	45.58	0.306	0.312
	C$_1$	**F$_0$**	3.37	3.42	0.418	0.426	3.15	3.21	46.76	47.45	0.367	0.374
		F$_1$	3.61	3.68	0.450	0.459	3.38	3.44	47.96	48.71	0.391	0.395
	C$_2$	**F$_0$**	3.26	3.32	0.410	0.418	3.05	3.10	46.48	47.32	0.353	0.360
		F$_1$	3.52	3.56	0.439	0.443	3.32	3.38	47.61	48.37	0.383	0.391
	C$_3$	**F$_0$**	3.15	3.22	0.398	0.406	2.98	3.03	45.99	46.97	0.342	0.350
		F$_1$	3.45	3.50	0.430	0.434	3.24	3.30	47.26	47.97	0.374	0.381
I$_3$	**C$_0$**	**F$_0$**	2.25	2.30	0.283	0.289	2.22	2.26	40.91	41.38	0.213	0.217
		F$_1$	2.27	2.32	0.288	0.293	2.26	2.30	41.01	41.84	0.218	0.221
	C$_1$	**F$_0$**	2.45	2.50	0.310	0.316	2.39	2.44	42.41	43.04	0.243	0.248
		F$_1$	2.72	2.78	0.340	0.347	2.59	2.62	44.10	44.68	0.282	0.285
	C$_2$	**F$_0$**	2.33	2.36	0.301	0.308	2.31	2.35	41.54	42.12	0.224	0.228
		F$_1$	2.62	2.68	0.332	0.339	2.51	2.56	43.09	43.78	0.272	0.277
	C$_3$	**F$_0$**	2.30	2.33	0.291	0.298	2.29	2.33	41.22	42.03	0.220	0.224
		F$_1$	2.52	2.57	0.320	0.323	2.44	2.49	42.76	43.44	0.257	0.262
LSD $_{at\ 5\%}$			**0.18**	**0.16**	**0.009**	**0.005**	**0.15**	**0.08**	**0.97**	**2.32**	**0.005**	**0.006**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

The interaction between irrigation, organic fertilization, and melatonin spraying revealed that the combination of full irrigation **(I$_1$),** plant compost (**C**$_1$) and melatonin (**F**$_1$) produced the best growth outcomes and head parameters. This combination optimally supports lettuce growth under favorable and stress conditions. Under the most restrictive irrigation (**I₃**), the addition of plant compost and melatonin still improved growth outcomes, but overall performance remained lower compared to higher irrigation levels, highlighting the critical role of water availability. Overall, the data underscores the importance of adequate irrigation, the beneficial impact of organic fertilization, and the potential of melatonin to enhance growth performance and stress tolerance in crisphead lettuce.

Table 5. Impact of different irrigation regimes, along with different organic fertilization treatments and spraying melatonin on growth performance of crisphead lettuce during seasons of 2022and 2023.

Treatments			Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaf area, cm^2 plant^{-1}		Relative water content, %	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation treatments										
I_1: 100% of ET_O			1308.83a	1326.54a	351.86a	351.86a	2492.33a	2526.08a	92.05a	93.73a
I_2: 80% of ET_O			1143.29b	1158.75b	311.35b	311.35b	2267.58b	2296.04b	88.64b	90.46b
I_3: 60% of ET_O			855.46c	866.17c	226.91c	226.91c	1751.71c	1777.25c	81.70c	83.27c
Organic fertilization treatments										
C_0: Control (without)			955.33c	967.78d	255.31d	255.31d	1919.22d	1945.39d	84.05d	85.81c
C_1: Plant compost (10 ton			1168.33a	1183.89a	318.39a	318.39a	2299.28a	2327.33a	89.26a	91.00a
C_2: ChM compost (10 ton			1160.56a	1174.83b	309.80b	309.80b	2255.17b	2287.11b	88.56b	90.29ab
C_3: Vermicompost (10 ton			1125.89b	1142.11c	303.34c	303.34c	2208.50c	2239.33c	87.99c	89.53b
Foliar application treatments										
F_0: Control (without)			1080.61b	1094.64b	287.05b	287.05b	2111.36b	2138.53b	86.68b	88.37b
F_1: Melatonin (70 mmol L$^-$			1124.44a	1139.67a	306.36a	306.36a	2229.72a	2261.06a	88.25a	89.94a
Interaction										
I_1	**C_0**	**F_0**	1051.33	1067.67	283.05	283.05	2097.33	2127.67	86.36	87.89
		F_1	1110.00	1124.33	292.56	292.56	2161.33	2185.33	87.22	88.71
	C_1	**F_0**	1405.00	1423.67	374.52	374.52	2607.00	2634.00	94.05	95.67
		F_1	1418.67	1435.00	384.96	384.96	2701.33	2735.00	94.57	96.47
	C_2	**F_0**	1399.67	1415.00	365.16	365.16	2556.67	2595.67	93.31	95.11
		F_1	1412.33	1429.33	380.31	380.31	2669.00	2714.67	94.30	96.29
	C_3	**F_0**	1264.67	1284.67	356.23	356.23	2509.00	2539.00	92.49	94.09
		F_1	1409.00	1432.67	378.05	378.05	2637.00	2677.33	94.13	95.64
I_2	**C_0**	**F_0**	948.33	959.33	264.03	264.03	1997.33	2026.00	84.67	87.09
		F_1	952.33	968.00	274.42	274.42	2067.33	2099.00	85.55	87.45
	C_1	**F_0**	1197.67	1214.33	320.04	320.04	2322.33	2350.33	89.40	91.59
		F_1	1255.00	1274.33	348.24	348.24	2456.33	2485.00	91.72	93.42
	C_2	**F_0**	1181.00	1195.67	310.98	310.98	2271.67	2304.67	88.64	90.24
		F_1	1240.00	1254.33	339.17	339.17	2434.00	2461.00	90.96	92.58
	C_3	**F_0**	1140.00	1156.33	303.26	303.26	2212.67	2236.67	87.86	89.49
		F_1	1232.00	1247.67	330.68	330.68	2379.00	2405.67	90.33	91.81
I_3	**C_0**	**F_0**	831.00	838.67	206.94	206.94	1573.33	1592.33	80.11	81.69
		F_1	839.00	848.67	210.83	210.83	1618.67	1642.00	80.40	82.02
	C_1	**F_0**	851.33	862.67	228.03	228.03	1781.00	1800.33	81.83	83.12
		F_1	882.33	893.33	254.52	254.52	1927.67	1959.33	84.00	85.71
	C_2	**F_0**	849.33	860.00	217.43	217.43	1728.00	1747.67	80.83	82.45
		F_1	881.00	894.67	245.73	245.73	1871.67	1899.00	83.30	85.05
	C_3	**F_0**	848.00	857.67	214.94	214.94	1680.00	1708.00	80.61	81.99
		F_1	861.67	873.67	236.86	236.86	1833.33	1869.33	82.55	84.17
LSD $_{at\ 5\%}$			**26.04**	**6.89**	**6.20**	**14.88**	**47.62**	**17.06**	**0.53**	**1.69**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Table 6. Impact of different irrigation regimes, along with different organic fertilization treatments and spraying melatonin on head traits of crisphead lettuce during seasons of 2022 and 2023.

Treatments			Head weight,		Head diameter,		Head height,		No. of outer	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation treatments										
I1: 100% of ETO			1124.38a	1138.13a	22.88a	23.38a	21.25a	21.59a	9.79a	12.54a
I2: 80% of ETO			955.67b	967.63b	21.33b	21.73b	19.58b	19.90b	8.33b	11.29b
I3: 60% of ETO			653.67c	661.29c	17.71c	18.08c	16.60c	16.89c	6.33c	8.58c
Organic fertilization treatments										
C0: Control (without)			770.50d	779.78d	18.93d	19.33c	17.51d	17.81c	6.89c	9.44b
C1: Plant compost (10 ton			972.56a	984.44a	21.53c	22.04a	20.03a	20.41a	8.89a	11.56a
C2: ChM compost (10 ton			962.72b	973.67b	21.19b	21.53b	19.62b	19.89ab	8.61ab	11.22a
C3: Vermicompost (10 ton			939.17c	951.50c	20.89a	21.35b	19.41c	19.72a	8.22b	11.00a
Foliar application treatments										
F0: Control (without)			890.53b	901.42b	20.23b	20.66b	18.76b	19.06b	7.81b	10.42b
F1: Melatonin (70 mmol L^{-1})			931.94a	943.28a	21.05a	21.47a	19.53a	19.85a	8.50a	11.19a
Interaction										
I1	**C0**	**F0**	891.33	904.33	20.40	20.97	18.57	18.90	7.67	10.67
		F1	914.00	924.00	20.70	21.10	18.80	19.07	8.00	11.00
	C1	**F0**	1209.00	1224.33	23.60	24.10	22.00	22.53	10.33	13.00
		F1	1225.00	1238.00	24.27	25.03	22.80	23.20	11.33	13.67
	C2	**F0**	1198.67	1209.67	23.30	23.80	21.60	21.83	10.00	12.67
		F1	1219.33	1231.33	24.07	24.43	22.50	22.77	11.00	13.33
	C3	**F0**	1121.33	1136.33	22.90	23.40	21.40	21.70	9.33	12.67
		F1	1216.33	1237.00	23.80	24.20	22.30	22.70	10.67	13.33
I2	**C0**	**F0**	758.33	767.33	19.40	19.70	18.00	18.23	7.33	10.00
		F1	784.00	795.33	19.80	20.03	18.37	18.70	7.67	10.33
	C1	**F0**	995.33	1007.67	21.70	22.00	19.93	20.33	8.67	11.67
		F1	1071.33	1087.00	22.60	23.17	20.90	21.23	9.00	12.33
	C2	**F0**	982.00	995.33	21.50	21.90	19.40	19.67	8.33	11.33
		F1	1055.67	1067.33	22.40	22.77	20.53	20.87	9.00	12.00
	C3	**F0**	952.33	966.67	21.20	21.77	19.20	19.53	8.00	11.00
		F1	1046.33	1054.33	22.00	22.50	20.30	20.60	8.67	11.67
I3	**C0**	**F0**	634.67	640.33	16.50	16.90	15.50	15.80	5.00	7.00
		F1	640.67	647.33	16.80	17.31	15.80	16.13	5.67	7.67
	C1	**F0**	651.33	657.00	17.97	18.47	16.90	17.13	6.67	8.67
		F1	683.33	692.67	19.07	19.47	17.67	18.00	7.33	10.00
	C2	**F0**	647.00	655.00	17.30	17.47	16.40	16.63	6.33	8.33
		F1	673.67	683.33	18.60	18.80	17.30	17.60	7.00	9.67
	C3	**F0**	645.00	653.00	16.97	17.40	16.17	16.43	6.00	8.00
		F1	653.67	661.67	18.50	18.83	17.10	17.37	6.67	9.33
LSD at 5%			**4.98**	**22.01**	**0.43**	**2.07**	**0.34**	**1.50**	**1.80**	**1.34**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

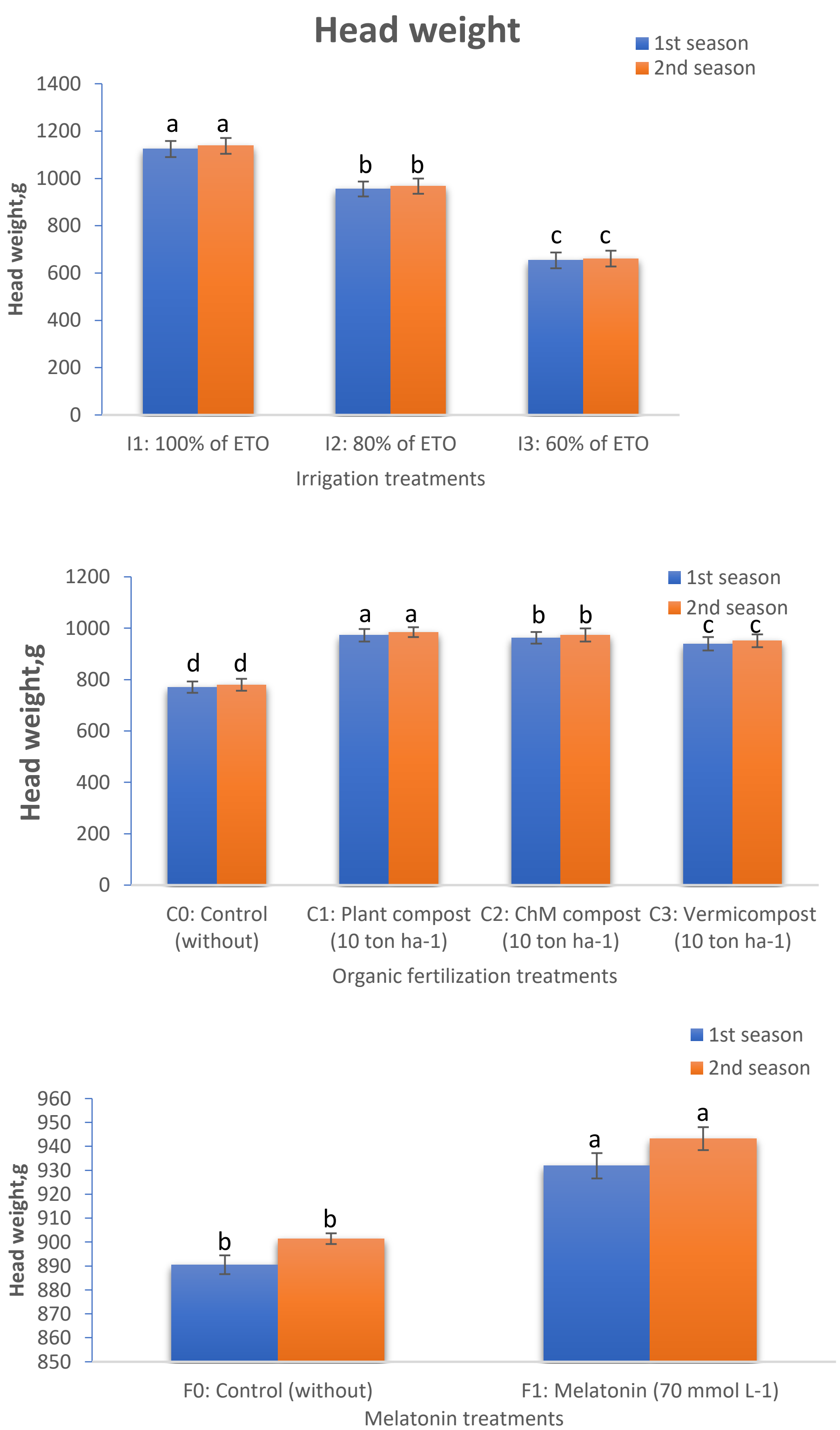

Fig. 2. Effect of the studied treatment on head weight during both studied seasons.

3.4 Head quality parameters

Table 7 summarizes the effects of the studied treatments on head quality parameters, including total carbohydrates, protein, total sugar, fiber, total dissolved solids, dry mater, vitamin C and vitamin E. Water stress generally reduced head quality, with lower values of all aforementioned traits observed under 60% ETO. However, organic fertilizers, especially plant compost, improved head quality traits, likely due to enhanced nutrient availability and water retention. ChM compost came the second order, while the vermicompost treatment came in the third order. The last order was set to control group. Melatonin application positively influenced head quality. This indicates melatonin's potential role in enhancing the nutritional value and stress resilience of lettuce heads, contributing to better quality produce under adverse conditions.

The interaction between irrigation levels, organic fertilizers and melatonin applications reveals that the highest values of total carbohydrates, protein, total sugar, fiber, total dissolved solids, dry mater, vitamin C and vitamin E were recorded under the combination of full irrigation with plant compost and melatonin application. Even under reduced irrigation levels, the combination of organic fertilization and melatonin substantially improved plant nutrient and pigment levels, underscoring the synergistic benefits of these treatments.

Table 7. Impact of different irrigation regimes, along with different organic fertilization treatments and spraying melatonin on quality parameters of crisphead lettuce during seasons of 2022and 2023

Treatments			Carbohydrates, %		Protein, %		T. Sugar,%		Fiber,%		TDS,%	
			1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation treatments												
I_1: 100% of ET_O			2.25a	3.26a	3.22a	2.28a	1.21a	1.25a	1.74a	1.77a	6.50a	6.57a
I_2: 80% of ET_O			1.99b	2.88b	2.84b	2.03b	0.93b	0.96b	1.44b	1.46b	5.81b	5.86b
I_3: 60% of ET_O			1.45c	2.24c	2.21c	1.50c	0.38c	0.40c	0.81c	0.82c	3.99c	4.04c
Organic fertilization treatments												
C_0: Control (without)			1.62c	2.44d	2.41d	1.58c	0.57d	0.59d	1.00d	1.02d	4.70d	4.75d
C_1: Plant compost (10			2.05a	2.98a	2.94a	2.11a	0.99a	1.01a	1.50a	1.53a	5.80a	5.87a
C_2: ChM compost (10			1.99ab	2.91b	2.87b	2.05ab	0.94b	0.97b	1.43b	1.46b	5.70b	5.73b
C_3: Vermicompost (10			1.94b	2.84c	2.80c	2.00b	0.88c	0.90c	1.38c	1.40c	5.53c	5.60c
Foliar application treatments												
F_0: Control (without)			1.83b	2.70b	2.67b	1.89b	0.78b	0.80b	1.25b	1.27b	5.24b	5.31b
F_1: Melatonin (70 mmol			1.96a	2.88a	2.84a	1.98a	0.91a	0.94a	1.41a	1.43a	5.63a	5.68a
Interaction												
I_1	**C_0**	**F_0**	1.80	2.68	2.65	1.88	0.75	0.78	1.18	1.21	5.37	5.42
		F_1	1.87	2.69	2.66	1.59	0.82	0.85	1.26	1.28	5.56	5.62
	C_1	**F_0**	2.39	3.45	3.41	2.45	1.36	1.39	1.91	1.94	6.90	6.98
		F_1	2.50	3.59	3.55	2.57	1.47	1.52	2.04	2.07	7.01	7.10
	C_2	**F_0**	2.32	3.36	3.31	2.38	1.28	1.33	1.85	1.87	6.69	6.77
		F_1	2.44	3.55	3.51	2.52	1.46	1.49	1.97	2.01	6.98	7.04
	C_3	**F_0**	2.28	3.28	3.23	2.34	1.21	1.25	1.79	1.82	6.50	6.61
		F_1	2.41	3.49	3.45	2.47	1.37	1.42	1.95	1.98	6.95	7.02
I_2	**C_0**	**F_0**	1.67	2.54	2.50	1.74	0.64	0.66	1.09	1.11	4.90	4.97
		F_1	1.74	2.62	2.58	1.57	0.68	0.70	1.14	1.16	5.14	5.22
	C_1	**F_0**	2.06	2.91	2.88	2.12	0.99	1.02	1.50	1.53	5.95	6.02
		F_1	2.23	3.18	3.14	2.31	1.16	1.19	1.72	1.75	6.35	6.43
	C_2	**F_0**	1.99	2.84	2.81	2.07	0.93	0.96	1.43	1.45	5.84	5.89
		F_1	2.17	3.12	3.08	2.23	1.13	1.16	1.67	1.70	6.46	6.33
	C_3	**F_0**	1.94	2.79	2.75	2.00	0.88	0.91	1.36	1.36	5.72	5.82
		F_1	2.12	3.03	2.99	2.19	1.04	1.07	1.59	1.62	6.10	6.18
I_3	**C_0**	**F_0**	1.30	2.04	2.02	1.35	0.25	0.26	0.65	0.66	3.58	3.61
		F_1	1.34	2.07	2.05	1.38	0.28	0.29	0.69	0.70	3.65	3.69
	C_1	**F_0**	1.47	2.27	2.24	1.52	0.39	0.40	0.81	0.83	3.89	3.96
		F_1	1.63	2.48	2.45	1.68	0.55	0.57	1.02	1.04	4.70	4.75
	C_2	**F_0**	1.41	2.17	2.14	1.45	0.33	0.34	0.74	0.76	3.80	3.86
		F_1	1.59	2.40	2.37	1.64	0.50	0.52	0.94	0.96	4.43	4.49
	C_3	**F_0**	1.36	2.13	2.10	1.41	0.30	0.31	0.72	0.73	3.71	3.75
		F_1	1.53	2.33	2.30	1.59	0.45	0.47	0.87	0.88	4.18	4.23
LSD at 5%			**0.15**	**0.06**	**0.05**	**0.23**	**0.09**	**0.05**	**0.14**	**0.07**	**0.15**	**0.14**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Cont. Table 7.

Treatments			D.M %		V.C, mg 100g^{-1}		V.E, mgkg^{-1}	
			1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation treatments								
I_1: 100% of ET_O			7.17a	7.27a	3.93a	3.98a	4.53a	4.57a
I_2: 80% of ET_O			6.42b	6.54b	3.39b	3.44b	3.78b	3.82b
I_3: 60% of ET_O			5.01c	5.06c	2.36c	2.40c	2.39c	2.43c
Organic fertilization treatments								
C_0: Control (without)			5.45d	5.51d	2.70d	2.71d	2.84d	2.84d
C_1: Plant compost (10 ton ha^{-1})			6.64a	6.70a	3.51a	3.57a	3.94a	4.01a
C_2: ChM compost (10 ton ha^{-1})			6.43b	6.56b	3.39b	3.45b	3.77b	3.84b
C_3: Vermicompost (10 ton ha^{-1})			6.30c	6.40c	3.31c	3.35c	3.71c	3.75c
Foliar application treatments								
F_0: Control (without)			6.04b	6.11b	3.10b	3.15b	3.40b	3.43b
F_1: Melatonin (70 mmol L^{-1})			6.36a	6.47a	3.35a	3.40a	3.73a	3.79a
Interaction								
I_1	**C_0**	**F_0**	5.92	5.94	3.00	2.98	3.26	3.13
		F_1	6.05	6.01	3.14	3.05	3.42	3.33
	C_1	**F_0**	7.59	7.74	4.27	4.34	4.98	5.08
		F_1	7.74	7.88	4.36	4.43	5.09	5.20
	C_2	**F_0**	7.43	7.56	4.11	4.18	4.78	4.86
		F_1	7.70	7.85	4.32	4.40	5.04	5.15
	C_3	**F_0**	7.29	7.41	3.98	4.06	4.62	4.69
		F_1	7.64	7.78	4.30	4.37	5.01	5.12
I_2	**C_0**	**F_0**	5.57	5.69	2.81	2.86	2.93	2.99
		F_1	5.75	5.87	2.91	2.94	3.12	3.18
	C_1	**F_0**	6.59	6.71	3.52	3.58	3.94	4.01
		F_1	7.14	7.25	3.89	3.96	4.43	4.53
	C_2	**F_0**	6.39	6.52	3.37	3.42	3.75	3.81
		F_1	6.97	7.14	3.76	3.83	4.14	4.20
	C_3	**F_0**	6.22	6.18	3.24	3.19	3.59	3.50
		F_1	6.75	6.92	3.64	3.72	4.31	4.37
I_3	**C_0**	**F_0**	4.68	4.78	2.15	2.22	2.15	2.21
		F_1	4.71	4.77	2.18	2.19	2.18	2.18
	C_1	**F_0**	5.30	5.06	2.37	2.41	2.37	2.41
		F_1	5.44	5.53	2.68	2.73	2.80	2.86
	C_2	**F_0**	4.77	4.86	2.23	2.27	2.22	2.26
		F_1	5.31	5.41	2.58	2.62	2.67	2.74
	C_3	**F_0**	4.75	4.85	2.20	2.24	2.20	2.24
		F_1	5.14	5.24	2.47	2.52	2.51	2.56
LSD at 5%			**0.24**	**0.15**	**0.08**	**0.09**	**0.22**	**0.08**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

4. Discussion

The results from the study indicate that various irrigation regimes, organic fertilization treatments, and foliar application of melatonin significantly affect the quality and growth of crisphead lettuce. Here are the scientific reasons behind the observed results:

4.1 Enzymatic antioxidants

Adequate water supply (Full Irrigation**, I_1)** ensures optimal physiological and metabolic functions in plants, leading to enhanced antioxidant enzyme activity. This increases the plant's ability to scavenge reactive oxygen species (ROS) generated during photosynthesis, especially under stress conditions. Reduced Irrigation **(I_2, I_3** expressed water stress) generally increased oxidative stress, but moderate stress **(I_2)** may still maintain sufficient enzymatic antioxidant levels. Severe water stress **(I_3)** reduces antioxidant capacity, leading to cellular damage and reduced plant growth and quality. The obtained results agree with those of **Elsherpiny and Helmy (2022) and Ghazi *et al.* (2023)**.

Plant Compost **(C_1)** provided essential nutrients and enhanced soil microbiota, leading to increased production of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD). These enzymes protect plants from oxidative stress. Chiken manure compost (ChM) and vermicompost **(C_2, C_3)** amendments may have improved soil structure and nutrient availability, enhancing antioxidant enzyme activities but to a lesser extent compared to plant compost. These results are in harmony with those of **Abumere *et al*. (2019);Elsherpiny, (2023);** .**Kareem and Hamed (2024); Elsaied *et al.* (2024).** Melatonin acts as a powerful antioxidant, directly scavenging free radicals and upregulating antioxidant enzyme activities, thus enhancing the plant's ability to cope with abiotic stress and improving overall plant health. These results are in accordance with those of **Sadak *et al.* (2020)**; **Elsherpiny *et al*. (2024)**; **Elsaied *et al.* (2024).**

4.2 Leaves chemical constituents and photosynthetic pigments

Full Irrigation **(I_1)** supported higher concentrations of chlorophyll and carotenoids, which are crucial for efficient photosynthesis. Adequate water availability ensures proper nutrient uptake (NPK) and optimal functioning of photosynthetic machinery. Reduced Irrigation **(I_2, I_3)** may have led to decreased chlorophyll content and impaired photosynthetic capacity due to stomatal closure and reduced carbon dioxide assimilation under water stress. These findings align with the results reported by **Elsherpiny and Helmy (2022) and Ghazi *et al.* (2023)**.

Plant Compost **(C_1)** may have increased the availability of macro and micronutrients, improving nutrient absorption, enhancing chlorophyll synthesis and maintaining high levels of essential nutrients such as nitrogen, phosphorus, and potassium, which are critical for photosynthetic efficiency (**Abd El-Hady *et al.* 2021**). ChM and vermicompost **(C_2, C_3)** also may have improved chlorophyll content but are slightly less effective than plant compost. These results are in harmony with those of **Abumere *et al*. (2019);**.**Elsherpiny, (2023);** .**Kareem and Hamed (2024); Elsaied *et al.* (2024).**

Melatonin Foliar Application **(F_1)** may have enhanced the synthesis of chlorophyll and other pigments by protecting the photosynthetic apparatus from oxidative damage, thereby improving photosynthetic efficiency and plant growth (**El-Bauome *et al.* 2022, 2024**). These results align with the findings of **Sadak *et al.* (2020)**; **Elsherpiny *et al*. (2024)**; **Elsaied *et al.* (2024).**

4.3 Growth criteria and head traits

Full Irrigation **(I_1)** resulted in optimal cell expansion and division, leading to better growth and larger head size. Sufficient water supports metabolic activities essential for growth. Reduced Irrigation **(I_2, I_3)** caused reduced cell turgor and impaired growth due to limited water availability, resulting in smaller head size and less biomass. The results obtained are consistent with those reported by **Elsherpiny and Helmy (2022) and Ghazi *et al.* (2023)**. Plant Compost **(C_1) may have** supplied a steady release of nutrients, enhancing root development and nutrient uptake, which supports robust plant growth and improved head traits. ChM and vermicompost **(C_2, C_3)** also may have improved soil fertility and structure, contributing to better growth but slightly less effective compared to plant compost. These results are in harmony with those of **Abumere *et al*. (2019);**.**Elsherpiny, (2023);** .**Kareem and Hamed (2024); Elsaied *et al.* (2024).** Melatonin foliar application **(F_1)** may have promoted growth by reducing stress-induced damage and enhancing cell division and elongation, leading to improved head size and weight. These results are in accordance with those of **Sadak *et al.* (2020)**; **Elsherpiny *et al*. (2024)**; **Elsaied *et al.* (2024).**

4.4 Head quality parameters

Full Irrigation **(I_1)** ensured high-quality lettuce heads with better carbohydrate, protein, sugar content, and improved texture due to optimal metabolic activity and nutrient translocation. Reduced Irrigation **(I_2, I_3)** decreased quality parameters due to restricted nutrient movement and metabolic disruptions caused by water stress. The obtained results agree with those of **Elsherpiny and Helmy (2022) and Ghazi *et al.* (2023)**. Plant Compost **(C_1)** may have improved head quality by enhancing nutrient content and availability, resulting in higher carbohydrate, protein, and sugar concentrations in lettuce heads. ChM and vermicompost **(C_2, C_3)** contributed to improved quality but are slightly less effective than plant compost in enhancing nutrient density and head quality. These results are in harmony with those of **Abumere *et al*. (2019);.Elsherpiny, (2023); .Kareem and Hamed (2024); Elsaied *et al.* (2024).** Melatonin foliar application **(F_1)** may have enhanced head quality by improving nutrient assimilation and reducing oxidative damage, leading to better texture, taste, and nutritional value of lettuce heads. These results are in accordance with those of **Sadak *et al.* (2020)**; **Elsherpiny *et al*. (2024)**; **Elsaied *et al.* (2024).** Overall, the combination of optimal irrigation, organic fertilization, and melatonin application synergistically improves lettuce quality by enhancing physiological processes, nutrient availability, and stress resilience.

5. Conclusion

This study underscores that optimizing irrigation regimes, incorporating organic fertilization, and applying melatonin significantly enhance the quality and growth of crisphead lettuce. Specifically, irrigation at 100% ET_O combined with plant compost and foliar melatonin treatment delivered the most favorable outcomes, boosting enzymatic antioxidant activity, improving leaf chemical constituents, enhancing photosynthetic pigments, and optimizing growth and head quality parameters. In the context of water scarcity in Egypt, using 80% of the ETO for irrigation with the application of organic fertilization is a practical approach to conserve water while still achieving satisfactory lettuce growth and quality. as the application of organic fertilization under irrigation level 80% achieved better than 100% without organic fertilization. The research highlights the crucial role of organic fertilizers and melatonin in augmenting plant tolerance to drought conditions. These practices not only enhance enzymatic and photosynthetic efficiency but also improve plant resilience to water stress. Implementing these methods can support agricultural productivity and food security in arid and semi-arid regions, maintaining crop quality and yield despite limited water availability. Future research should focus on the long-term impacts of these treatments in various soil types and climates, and explore the potential of integrating additional biostimulants with melatonin to further improve crop resilience and productivity.

Conflicts of interest: The authors have declared that no competing interests exist.

Formatting of funding sources: The research was funded by the personal efforts of the authors.

References

Abd El-Hady, M. A. M., Doklega, S. M. A., & El-Ezz, S. A. (2021). Influence of organic and potassium fertilization on potato yield and quality. Plant Archives, 21(Supplement 1), 560-568.

Abumere, V. I., Dada, O. A., Adebayo, A. G., Kutu, F. R., & Togun, A. O. (2019). Different rates of chicken manure and NPK 15-15-15 enhanced performance of sunflower (*Helianthus annuus* L.) on ferruginous soil. International Journal of Agronomy, 2019(1), 3580562.

AOAC, (2000).˝Official Methods of Analysis˝. 18th Ed. Association of Official Analytical Chemists, Inc., Gaithersburg, MD, Method 04.

CoStat version 6.303 copyright (1998-2004). CoHort Software 798 Lighthouse Ave. PMB 320, Monterey, CA, 93940, USA.

Dere, Ş., Güneş, T., & Sivaci, R. (1998). Spectrophotometric determination of chlorophyll-A, B, and total carotenoid contents of some algae species using different solvents. Turkish Journal of Botany, 22(1), 13-18.

Doklega, S. M. A., Saudy, H. S., El-Sherpiny, M. A., Abou El-Yazied, A., AbdEl-Gawad, H. G., Ibrahim, M. F. M.; Abd El-Hady, M. A. M.,Omar, M. M. A., & Metwally, A. A. (2023). Rhizospheric addition of hydrogel polymer and zeolite plus glutathione mitigate the hazard effects of water deficiency on common bean plants through enhancing the defensive antioxidants. *Journal of Crop Health*, *76*(1), 235-249.

Elavarthi, S., & Martin, B. (2010). Spectrophotometric assays for antioxidant enzymes in plants. Plant stress tolerance: methods and protocols, 273-280.

El-Bauome, H. A., Abdeldaym, E. A., Abd El-Hady, M. A., Darwish, D. B. E., Alsubeie, M. S., El-Mogy, M. M., ... & Doklega, S. M. (2022). Exogenous proline, methionine, and melatonin stimulate growth, quality, and drought tolerance in cauliflower plants. *Agriculture*, *12*(9), 1301.

El-Bauome, H. A., Doklega, S. M., Saleh, S. A., Mohamed, A. S., Suliman, A. A., & Abd El-Hady, M. A. (2024). Effects of melatonin on lettuce plant growth, antioxidant enzymes and photosynthetic pigments under salinity stress conditions. Folia Hort., 36(1): 1–17.

Elsaied, M. S., Rakha, M., & Elaidy, F. (2024). Enhancing Head Lettuce Growth and Quality under Water Stress with Proline, Melatonin and Vermicompost Applications. Egyptian Journal of Soil Science, 64(3).

Elsherpiny, M. A. (2023). Role of compost, biochar and sugar alcohols in raising the maize tolerance to water deficit conditions. Egyptian Journal of Soil Science, 63(1), 67-81.

Elsherpiny, M. A., & Helmy, A. (2022). Response of maize plants grown under water deficit stress to compost and melatonin under terraces and alternate furrow irrigation techniques. Egyptian Journal of Soil Science, 62(4), 383-394.

Elsherpiny, M.A., Baddour,A.G., & Kaney, M. (2024). Improving crisphead lettuce productivity grown under water deficit conditions through biochar and zeolite soil amendments, coupled with foliar stimulant applications under a drip irrigation system. Egyptian Journal of Soil Science, 64(2). 643-660.

Garnier, E., Shipley, B., Roumet, C., & Laurent, G. (2001). A standardized protocol for the determination of specific leaf area and leaf dry matter content. Functional ecology, 688-695.

Ghazi, D., Hafez, S., & Elsherpiny, M. A. (2023). Rice cultivation adaption to water resources shortage in Egypt. Egyptian Journal of Soil Science, 63(1), 113-126.

Gomez; K. A., & Gomez, A.A (1984). “Statistical Procedures for Agricultural Research”. John Wiley and Sons, Inc., New York.pp:680.

Kareem, S. S., & Hamed, B. A. (2024). The effect of adding bio and organic fertilizer under two levels of water stress on the readiness of NPK nutrients in the plant and the growth yield of the sorghum plant. In IOP Conference Series: Earth and Environmental Science (Vol. 1371, No. 8, p. 082010). IOP Publishing.

Mostafa, N. A., El-Sherpiny, M. A., Elmakarm, A., & Amira, A. (2023). Impact of organic fertilization and some beneficial elements on the performance and storability of salt-stressed crisphead lettuce (*Lactuca sativa* L.). Journal of Plant Production, 14(12), 403-409.

Peterburgski, A. V. (1968)."Handbook of Agronomic Chemistry". Kolos Publishing House, Moscow,(in Russian, pp. 29-86).

Sadak, M. S., Abdalla, A. M., Abd Elhamid, E. M., & Ezzo, M. I. (2020). Role of melatonin in improving growth, yield quantity, and quality of *Moringa oleifera* L. plant under drought stress. Bulletin of the National Research Centre, 44(1), 1-13.

Saeed, A. M., Hamzah, M. J., & Ali, N. J. M. (2018). Sensitive spectrophotometric method for determination of vitamins (C and E). International Journal of Pharmaceutical Sciences and Research, 9(8), 3373-3377.

Tandon, H. L. S. (2005). Methods of analysis of soils, plants, waters, fertilisers & organic manures. Fertilizer Development and Consultation Organisation.

Uddling, J., Gelang-Alfredsson, J., Piikki, K., & Pleijel, H. (2007). Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. Photosynthesis research, 91, 37-46.

Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W. and Novozamsky, I. (2013). Plant analysis manual. Springer Science & Business Media.