Original Article

Growth And Physiological Responses of Sunflower Plants to Different Methyl Jasmonate Spray Concentrations, Irrigation Periods and Plant Stages

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Abstract

This field experiment investigated the Flami sunflower crop's physiological response to spraying of 0, 50, and 100 µmol methyl jasmonate (MeJA) concentrations at the 6-10 leaves and pre-flowering stages and the impact of 5, 9, and 13-day irrigation intervals. The experiment was conducted in a randomized complete block design (RCBD) with a split–split plot arrangement with three replicates. The 5-day irrigation interval achieved the best values for the studied growth and physiological indicators, followed by 6 and 13 days, respectively. The MeJA spray treatment enhanced plant growth, with the highest concentration achieving the best values, producing increases in LA by 8.01%, DW by 21.69%, CGR by 14.92%, RGR by 10.65%, NAR by 18.34%, Ch. a by 22.02%, Ch. b by 24.17%, RWC by 8.65%, and proline by 17.34%, while decreasing solute leakage by 47.93% compared to control. Overall, the best interaction for growth and physiological performance of the crop was obtained for the 5-day irrigation interval and 100 µmol MeJA spray combination at the pre-flowering stage.

Keywords: Concentration methyl jasmonate, Irrigation intervals, Spray stage, Physiological characteristics, Sunflower.

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Introduction

Sunflower (*Helianthus annuus* L.) is a member of the family Asteraceae. It has various uses, including oil extraction from oilseed cultivars and fodder. Sunflower cultivation in Iraq covers about 748 ha, producing 1909 tons (1). The global cultivation area is 27.87 million ha, producing 50.2 million tons. Sunflower oil is the fourth largest source of oil in the world, after palm oil, soybeans, and rapeseed. According to FAO statistics (14), the oil content in sunflower seeds can reach 55%. Sunflower seeds also contain a percentage of vitamins such as K, E, D, and A (30).

Abiotic stress arises when climatic and soil conditions hinder crop growth, with salinity, extreme temperatures, radiation, and drought being major factors degrading ecosystems (21). Drought is the most severe stress, intensifying other adverse effects with about 33% of global agricultural land being drought-prone, especially in arid and semi-arid regions (7). By 2050, over 50% of farmland may face

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drought stress. (35) highlighted that climate change has significantly reduced sunflower yields, mainly under drought. A study in Iraq (1) confirmed that higher temperatures and lower rainfall reduced sunflower plant height, leaf number, and seed yield, with autumn planting suffering more than spring due to prolonged drought and heat. This underscores the need to adopt climate-resilient agricultural practices that not only include selecting drought-tolerant cultivars and adjusting planting dates but also improving irrigation management through appropriate irrigation intervals. Also, the application of growth regulators such as methyl jasmonate (MeJA) can aid in enhancing plant drought resistance and maintaining productivity under changing environmental conditions.

Irrigation intervals play an important role in sunflower growth, yield, and quality. A study (16) in Sudan on the effect of different irrigation intervals on the vegetative growth of two hybrids of sunflowers found that frequent irrigation intervals (7 days) improved the vegetative growth (plant height, stem diameter, number of leaves per plant, leaf area index and shoot dry weight). The study (12) found that water deficit reduced the net assimilation rate to a different level in sunflowers than well-watered conditioners.

The foliar applications of growth regulators and mineral elements have been widely studied to enhance plant resilience under abiotic stress conditions. Similarly, this study investigated the role of MeJA in mitigating the adverse effects of prolonged irrigation intervals on sunflower growth and physiological traits. The exogenous application of certain substances as growth regulators, such as osmoprotectants and minerals is considered a feasible technique to cope with soil water deficit or deficit irrigation (8). Foliar spraying of the potential growth regulator jasmonic acid has been found to enhance defense against reactive oxygen species (ROS) by regulating relative water content, net assimilation rate, and stomatal conductance (28). Jasmonic acid also boosts chlorophyll content by protecting photosystems and the electron transport chain (14).

In particular, foliar application during the leaf development stage is physiologically important because it coincides with active leaf expansion and photosynthetic capacity building, directly influencing source strength and assimilate production. Additionally, application before the flowering stage is critical because this period represents a key phase for dry matter accumulation and translocation, making it a sensitive window where improved stress tolerance can significantly sustain growth and yield formation under drought conditions (8).

MeJA is a volatile phytohormone that contributes to many plants' critical processes, especially under biotic and abiotic stresses, and is noted to effectively regulate the biosynthesis of other plant hormones and/or enzymes. However, it specifically affects the plant’s antioxidant defense system (34).

A study by (32) on the effect of MeJA on the growth, physiological, and biochemical characteristics of barley varieties found improvements in relative water content (RWC), photosynthetic pigments, soluble sugar, and proline. (8) found that the exogenous application of jasmonic acid at concentrations of 40-80 ppm enhanced sunflower growth parameters under water-stressed conditions, which was closely linked to increased stomatal activity stimulated by the acid.

Thus, this research aimed to determine how MeJA, when sprayed at different growth stages, may mitigate the effects of drought stress and increase the dry matter yield according to particular physiological traits of sunflower crops.

Materials and Methods

This field experiment was conducted on the Flami oil variety sunflower crop at the College of Agriculture, University of Anbar, Iraq, in summer 2024. It examined the effect of MeJA at various stages of the plant's growth in mitigating the impact of drought stress and enhance dry matter results based on specific physiological characteristics of the crop. The experiment was conducted in a randomized complete block design (RCBD) with a split-plot arrangement, with the main plots allocated to the first factor (I: irrigation interval) at three levels of 5, 9, and 13 days. The second factor (S: spraying stage) was applied in the secondary plots (Subplot) and included two spraying stages: the 6-10 leaf and before-flowering stages. The third factor (C: concentration) involved the application of MeJA at three concentrations of 0, 50, and 100 µmol in the sub-sub plot.

The factorial design resulted in 18 treatment combinations per replicate (3 irrigation intervals × 2 spraying stages × 3 concentrations). With three replications, a total of 54 experimental units were established. Each plot measured 3 × 3 m², with 2 m between the main plots and replicates to prevent lateral movement of water and to ensure proper isolation during foliar spraying. Sowing was done in rows, with each plot containing five rows spaced 60 cm apart, and plants at 30 cm apart within rows, giving a final plant density of 55,555 plants ha^{-1} (15). Planting was carried out on 20/03/2024.

Irrigation water was sourced from the Euphrates River and was applied using a drip irrigation system with a discharge rate of 8 liters per hour per dripper, ensuring efficient and uniform water distribution throughout the plots. The same amount of water was applied per irrigation event across all treatments, maintaining a fixed irrigation volume, with only the interval between irrigations varying to create different levels of water availability and drought stress.

Prior to sowing, the field was prepared through plowing and harrowing, and a basal fertilizer application was made according to agronomic recommendations. Specifically, 80 kg ha^{-1} of di-ammonium phosphate (DAP) was incorporated during soil preparation, followed by the application of 240 kg ha^{-1} of urea, which was split into three equal doses during the growing season to ensure adequate nitrogen availability (3). Standard crop management practices were uniformly applied across all plots. This included pest control measures, such as controlling cutworm infestations, and thinning seedlings to one healthy plant per hill two weeks after sowing to ensure uniform plant stands. Weed control and any additional plant-care operations were carried out as needed throughout the growing season to maintain optimal growing conditions. The field soil's physical and chemical characteristics were measured from random samples taken at 0–30 cm depth at the start of the season before planting (Table 1).

Table 1. Some physical and chemical properties of the soil.

pH	**7.13**	**-**
EC	1327	µcm.m^{-1}
Available N	0.23	mg.kg^{-1}
Available P	63.3	mg.kg^{-1}
Available K	108.4	mg.kg^{-1}
NaCl	2.6	%
TDS	7439	ppm
Sand	59.0	%
Silt	12.0	%

Clay	29.0	%
Texture	Sandy clay	-

Five plants from the central rows of the experimental unit were randomly selected with the soil surrounding their roots after they completed flowering. The measurements that were taken were as follows:

Leaf area (LA): Measured at 20-day intervals during the growing period before and after spraying. For every replication, five plants were extracted from each experimental unit. Every plant's maximum leaf width was measured, and the squared value multiplied by a constant of 0.65, according to (17).

Dry weight (DW): Plant dry weight was calculated by drying the plant at 85 °C for 48 hours before and 20 days after spraying.

Crop growth rate (CGR): CGR =1/P * (dw/dt), according to Watson (33).

Relative growth rate (RGR): RGR = (Loge W2 - Loge W1) / (dt), according to Radford (26).

Net assimilation rate (NAR): NAR = [(W2-W) x (Loge L2- logeL1)] / [(dt) x (L2-L1)], according to Gregory (21)

where: P = Ground Area, dw = (W2- W1): the plant dry weight (g) at the first and second stage, L1: LA at the first stage, L2: LA at the second stage, dt =(t2 - t1) = time interval, Loge: Logarithm to the base.

Total Chlorophylls: Chlorophyll a and b content was determined by the Froze and Archioze method (19).

Relative water content (RWC): The uppermost fully expanded leaves were used for measurement of RWC using the following formula (10):

RWC % = 100 × (FW – DW) / (TW – DW).

FW: fresh weight, DW: dry weight, TW: turgid weight

Turgid weight was determined after 24 h rehydration at 4 °C in a dark room with the leaf discs placed in a container with distilled water, and dry weight was determined after oven drying for 24 h at 80 °C.

Soluble leakage (SL): After applying the experimental treatments at flowering, leaf disc samples were independently taken from each experimental plot's second and third fully elongated leaves. A predetermined and consistent quantity and weight of leaf discs were then placed in a plastic container with 10 ml of distilled water. After three hours of shaking the containers, a spectrophotometer measured the solution's initial absorption at a wavelength of 273 nm. After transferring the solutions from each container separately to test tubes with stoppers, they were placed in a water bath (boiling point) for half an hour. The solution's final absorption was then measured at the same wavelength. The following equation was applied (24):

Percentage of leached solutes (%) = (Initial absorption/ Final absorption) ×100

Proline (Pro. A) µmol g^{-1} FW: Proline content was quantified according to the method of (9).

Statistical Analysis: The collected data were subjected to analysis of variance (ANOVA) appropriate for the split–split plot design to determine the significance of the main effects and their interactions. The statistical analysis was performed using GenStat software package (VSN International Ltd.). Differences among treatment means were tested using the Least significant difference (LSD) test at a 5% probability level ($P \leq 0.05$) (5).

Results and Discussion

There were markedly significant differences ($P \leq 0.01$) between the different irrigation intervals, spraying stages, and methyl jasmonate concentrations for the LA, DW, CGR, and NAR growth indices while the RGR index ($P \leq 0.05$) for spray concentration had only significant difference. The interactions (irrigation intervals × stage of spraying, irrigation intervals × concentration, stage × concentration, and I×S×C) were highly significant only for LA and not for other indices (Table 2).

The 5-day irrigation interval achieved the best values for the studied growth indicators, with leaf areas of 7629.1 $cm^2.plant^{-1}$, dry weight at 60.33 $g.plant^{-1}$, crop growth rate of 11.63 $g.m^{-2}.d^{-1}$, relative growth rate of 9.99 $mg.g^{-1}.d^{-1}$, and net assimilation rate of 0.607 $mg.cm^{-2}.d^{-1}$. When the irrigations interval was extended from 5 to 13 days, the values reached the lowest levels at 6126.0 $cm^2.plant^{-1}$, 46.87 $g.plant^{-1}$, 6.79 $g.m^{-2}.d^{-1}$, 8.84 $mg.g^{-1}.d^{-1}$, and 0.323 $mg.cm^{-2}.d^{-1}$, respectively (Table 3).

The pre-flowering stage was significantly better than the six-leaf spraying stage, as the leaf area values reached 7059.7 $cm^2.plant^{-1}$, dry weight 57.37 $g.plant^{-1}$, and crop growth rate 9.74 $g.m^{-2}.d^{-1}$, relative growth rate 10.08 $mg.g^{-1}.d^{-1}$, and NAR 0.489 $mg.cm^{-2}.d^{-1}$ compared to the 6-leaf stage, which recorded 6761.2 $cm^2.plant^{-1}$, 49.81 $g.plant^{-1}$, 8.82 $g.m^{-2}.d^{-1}$, 9.00 $mg.g^{-1}.d^{-1}$, and 0.442 $mg.cm^{-2}.d^{-1}$, respectively (Table 3).

Methyl jasmonate concentration of 100 µmol produced substantial results for all growth parameters, as the LA values reached 7172.4 $cm^2.plant^{-1}$, DW 62.12 $g.plant^{-1}$, CGR 10.14 $g.m^{-2}.d^{-1}$, RGR 10.37 $mg.g^{-1}.d^{-1}$, and NAR 0.516 $mg.cm^{-2}.d^{-1}$ compared to control of 8.01, 21.69, 14.92, 10.65, and 18.34 %, respectively (Table 3).

As a result, the 5-day irrigation interval and spraying MeJA during pre-flowering at 100 µmol concentration was superior in all studied indicators, as the LA values reached 8083.3 $cm^2.plant^{-1}$, DW 72.93 $g.plant^{-1}$, CGR 13.08 $g.m^{-2}.d^{-1}$, RGR 11.05 $mg.g^{-1}.d^{-1}$,, and NAR 0.697 $mg.cm^{-2}.d^{-1}$ (Table 3).

Table 2. Mean of square and LSD indicator values in the sunflower plants under various treatments.

Source Variance	Mean Square				
	LA	DW	CGR	RGR	NAR
I	10226354**	815.23**	105.7172**	6.8318**	0.3635281**
S	1203108**	770.92**	10.4494**	15.8812**	0.0298762**
C	1518322.**	814.09**	11.3153**	5.2838*	0.0410724**
I*S	109622**	41.20ns	0.1031ns	0.1049ns	0.0004227ns
I*C	160652**	17.57ns	0.1062ns	0.1457ns	0.0004538ns
S*C	19565**	32.92ns	0.901ns	0.2063ns	0.0002703ns
I*S*C	144808**	19.28ns	0.0055ns	0.0254ns	0.0000143ns
$LSD_{0.05}$I	18.24	3.067	0.238	0.539	0.119
$LSD_{0.05}$S	14.89	2.504	0.194	0.440	0.009
$LSD_{0.05}$C	18.24	3.067	0.238	0.539	0.119
$LSD_{0.05}$I*S	25.79	4.337	0.336	0.762	0.017
$LSD_{0.05}$I*C	31.59	5.312	0.412	0.933	0.021
$LSD_{0.05}$S*C	25.79	4.337	0.336	0.762	0.017
$LSD_{0.05}$I*S*C	44.67	7.512	0.582	1.319	0.029

I – irrigation interval, S – spraying stage, C – MeJA concentration.

Table 3. Leaf area (LA), plant dry weight (DW), crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) values in sunflower plant under different treatments.

Treatment	LA $Cm^2.p^{-1}$	DW $g.p^{-1}$	CGR $g.m^{-2}.\ d^{-1}$	RGR $mg.\ g^{-1}.\ d^{-1}$	NAR $mg.cm^{-2}.\ d^{-1}$
Irrigation intervals					
I1 (5 days)	7629.1	60.33	11.63	9.99	0.607
I2 (9 days)	6976.2	53.57	9.43	9.79	0.467
I3 (13 days)	6126.0	46.87	6.79	8.84	0.323
Spraying stage					
S1 (6 leaves)	6761.2	49.81	8.82	9.00	0.442
S2 (pre-flowering)	7059.7	57.37	9.74	10.08	0.489
MeJA concentration					
C1 (0 µmol)	6598.1	48.65	8.63	9.26	0.421
C2 (50 µmol)	6960.8	55.44	9.08	9.76	0.452
C3 (100 µmol)	7172.4	62.12	10.14	10.37	0.516
Interaction					
I1S1C1	7075.7	51.53	10.63	9.26	0.542
I1S1C2	7409.2	54.29	10.81	9.36	0.562
I1S1C3	7822.5	63.02	11.93	9.98	0.635
I1S2C1	7165.7	53.46	11.51	10.05	0.589
I1S2C2	8218.5	66.73	11.82	10.25	0.616
I1S2C3	8083.3	72.93	13.08	11.05	0.697
I2S1C1	6467.1	41.41	8.31	8.73	0.402
I2S1C2	6923.9	49.61	8.71	9.15	0.431
I2S1C3	6951.9	54.29	9.76	9.68	0.493
I2S2C1	6910.2	50.55	9.21	9.85	0.448
I2S2C2	7046.8	57.33	9.58	10.27	0.474
I2S2C3	7557.6	68.25	10.97	11.06	0.556
I3S1C1	5905.5	40.67	5.81	7.73	0.269
I3S1C2	6005.7	43.86	6.37	8.40	0.301
I3S1C3	6289.2	49.63	7.08	8.68	0.343
I3S2C1	6064.6	42.90	6.44	8.57	0.300
I3S2C2	6160.8	51.09	7.09	9.42	0.336
I3S2C3	6330.0	53.06	7.95	10.22	0.386

There were statistically highly significant differences ($P \le 0.01$) between for the three treatment in all growth indicators, i.e., chlorophyll a (Ch. a), chlorophyll b (Ch. b), relative water content (RWC), soluble leakage (SL), and proline (Pro. A) except for the index pro. A ($P \le 0.05$) on spray stage where the differences were significant. The interactions (irrigation intervals × stage of spraying) were highly significant ($P \le 0.01$) for Ch. b, significant ($P \le 0.05$) for Ch. a and pro. A. were not significant for RWC and SL. The irrigation intervals × spray concentration interactions were highly significant ($P \le 0.01$) for Ch. a and Ch. b, significant ($P \le 0.05$) for RWC and SL and not significant for pro. A. At the same time, the stage × concentration interaction was not significant for all indices. The combined interaction (I×S×C) was highly significant for Ch. b, significant for SL and not significant for other indices (Table 4).

As for chlorophyll, the 5-day irrigation interval showed the best performance for the studied indicators. Values for Ch. a reached 27.82 $mg.g^{-1}$, Ch. b 37.54 $mg.g^{-1}$, RWC 85.60 %, SL 30.89 % (the least and best values) while the 13-day interval achieved the highest Pro. A 38.32 $\mu mol.g^{-1}$ FW. Increasing the period between irrigations from 5 to 13 days resulted in Ch. a declining from 27.82 $mg.g^{-1}$ to 10.58

mg.g^{-1}, Ch. b from 37.54 mg.g^{-1} to 13.45 mg.g^{-1}, and RWC from 85.60% to 69.09%. Meanwhile, soluble leakage (SL) and proline (Pro. A) increased significantly, with the former rising from 30.89% to 46.07% and Pro. from 21.80 µmol.g^{-1} FW to 38.32 µmol.g^{-1} FW (Table 5).

The spraying treatment in the pre-flowering stage significantly outperformed the 6-leaf stage. The values for chlorophyll a (Ch. a) reached 19.32 mg.g^{-1}, chlorophyll b (Ch. b) 25.53 mg.g^{-1}, relative water content (RWC) was 80.99%, and proline (Pro. A) was 30.38 µmol.g^{-1} FW. In comparison, the 6-leaf stage showed declines in Ch. a values of 17.68 mg.g^{-1}, Ch. b at 23.73 mg.g^{-1}, RWC at 76.15%, and Pro. at 29.25 µmol.g^{-1} FW, while soluble leakage (SL) was more favorable at 36.41%. Thus, the pre-flowering stage had higher values in Ch. a, Ch. b, RWC, and Pro. A, while SL was higher in the 6-leaf stage. When comparing the MeJA spray concentrations, the 100 µmol treatment was significantly superior to the 50 concentration and the control, as the Ch. a values reached 20.39 mg.g^{-1}, Ch. b 27.28 mg.g^{-1}, RWC 83.86 %, SL 31.83 % and Pro. A 34.67 µmol.g^{-1} FW compared to the control's 22.02, 24.17, 8.65, -47.94, and 17.34 %, respectively (Table 5).

As a result, the 5-day irrigation treatment and spraying with MeJA produced Ch. A of 34.43 mg.g^{-1}, Ch. b 47.93 mg.g^{-1}, RWC 92.36 %, SL 23.70 %. Meanwhile, the highest Pro. A content before flowering was at the 100 µmol MeJA concentration and 13-day irrigation interval and the Ch. values reached was 44.22 µmol.g^{-1} FW (Table 5).

Table 4. The mean of square and LSD values of chlorophyll a (Ch. a), chlorophyll b (Ch. b), relative water content (RWC), soluble leakage (SL), and proline (Pro. A) in sunflower plants under different treatments.

Source Variance	Mean Square				
	Ch. a	Ch. b	RWC	SL	Pro. A
I	1363.3791**	2651.6770**	1307.442**	1096.295**	1230.988**
S	36.4518**	43.7361**	316.031**	54.881**	17.110*
C	103.6395**	226.3480**	213.633**	258.58**	147.935**
I*S	3.9507*	16.2623**	0.404ns	3.858ns	23.631*
I*C	18.6013**	44.6928**	3.724*	18.061*	7.014ns
S*C	0.1270ns	1.9825ns	0.775ns	0.507ns	2.630ns
I*S*C	0.6391ns	5.4516**	0.758ns	18.046*	0.151ns
$LSD_{0.05}$I	0.589	0.602	0.823	1.298	1.389
$LSD_{0.05}$S	0.481	0.491	0.672	1.060	1.134
$LSD_{0.05}$C	0.589	0.602	0.823	1.298	1.389
$LSD_{0.05}$I*S	0.833	0.851	1.164	1.836	1.964
$LSD_{0.05}$I*C	1.021	1.042	1.426	2.249	2.406
$LSD_{0.05}$S*C	0.833	0.851	1.164	1.836	1.964
$LSD_{0.05}$I*S*C	1.444	1.474	2.017	3.180	3.402

I – irrigation interval, S – spraying stage, C – MeJA concentration.

Table 5. Chlorophyll a (Ch. a), chlorophyll b (Ch. b), relative water content (RWC), soluble leakage (SL), and proline (Pro. A) in sunflower plant under different treatments.

Treatment	Ch. a mg.g^{-1}	Ch. b mg.g^{-1}	RWC %	SL %	Pro. A µmol.g^{-1} FW
Irrigation intervals					
I1 (5 days)	27.82	37.54	85.60	30.89	21.80
I2 (9 days)	17.10	22.90	81.02	35.30	29.33
I3 (13 days)	10.58	13.45	69.09	46.07	38.32

		Spraying stage			
S1 (6 leaves)	17.68	23.73	76.15	36.41	29.25
S2 (pre-flowering)	19.32	25.53	80.99	38.43	30.38
		MJ concentration			
C1 (0 µmol)	15.90	20.68	76.15	47.08	28.66
C2 (50 µmol)	17.34	23.39	79.14	40.15	32.38
C3 (100 µmol)	20.39	27.28	83.36	31.83	34.67
		Interaction			
I1S1C1	23.19	30.71	78.79	33.95	20.00
I1S1C2	25.39	35.11	82.52	31.28	21.24
I1S1C3	30.83	40.92	87.93	23.07	23.44
I1S2C1	25.08	32.16	84.77	40.09	20.00
I1S2C2	27.98	38.38	87.23	33.29	21.79
I1S2C3	34.43	47.93	92.36	23.70	24.34
I2S1C1	14.79	19.20	76.09	39.90	26.85
I2S1C2	16.02	21.85	79.02	35.06	30.71
I2S1C3	18.48	25.75	81.21	27.87	31.58
I2S2C1	16.38	21.13	80.41	42.44	25.21
I2S2C2	17.04	23.25	83.08	36.14	29.94
I2S2C3	19.88	26.20	86.31	30.40	31.67
I3S1C1	9.08	12.19	63.13	56.98	32.84
I3S1C2	9.98	13.17	66.10	44.28	37.17
I3S1C3	11.34	14.63	70.57	35.32	39.44
I3S2C1	10.14	12.45	68.78	53.60	35.68
I3S2C2	11.10	13.49	71.21	46.86	40.57
I3S2C3	11.85	14.74	74.76	39.35	44.22

Water stress caused by increasing the intervals between irrigations has negative effects on plant growth, as mainly reflected in the decrease in leaf area and accumulation of dry matter in the plant. These results are in line with (4) who reported that the presence of jasmonates is crucial for the adaptive responses of sunflower to water deficit, as they regulate root system architecture and maintain physiological balance to sustain growth under stress conditions.

The results are also consistent with (8), which reported an increase in proline content under water deficit conditions as part of the plant's stress tolerance mechanisms. In such conditions, proline and other osmolytes function as osmotic regulators and protective compounds. Similar increases in proline levels in response to drought stress have also been documented in other studies (27, 29 and 31).

Leaf relative water content decreased according to water shortage. Osmoregulation between mesophyll tissues and transpiration is closely linked to relative water content, a fundamental indicator of a plant's ability to cope with low soil moisture levels. Reduced RWC in the 13-day irrigation interval is associated with decreased water transport via the xylem to the leaf cells due to reduced transpiration through the stomata. Water stress reduces turgor pressure at the cellular level, resulting in a decline in RWC in mesophyll and guard cells (20). Chlorophyll concentration is one of the major factors affecting photosynthetic capacity, and this study found that its content decreases under water shortage. These findings are consistent with (11, 13, 23 and 25) for sunflower.

The findings of this study showed that MeJA spraying enhanced the growth and physiological parameters of the plant under different irrigation intervals, and thus, its role in mitigating the negative effects of longer irrigation intervals were demonstrated.

Furthermore, MeJA application timings had a vital role in maximizing its positive effects, with the pre-flowering stage showing better results for improving chlorophyll content, relative water content, and dry matter accumulation compared to the six-leaf stage. These results are consistent with many previous studies, such as (6, 8, 14 and 32).

Moreover, (34) found that MeJA contributes to many critical processes in plants, especially under biotic and abiotic stresses, and to effectively regulate the biosynthesis of other plant hormones and enzymes, like superoxide dismutase (SOD). However, MeJA particularly affects the plant's antioxidant defense system. Its application enhances the water status of sunflower plants by boosting defensive biochemical activities and secondary metabolites to improve resilience. In this study, a significant increase in RWC was observed at the higher MeJA dose (100 µmol) under 5 and 13-day irrigation intervals, consistent with the findings of (٨).

Conclusion

This research demonstrated that exogenously applied MeJA plays a significant role in mitigating the adverse effects of drought stress on the morphological, physiological, and biochemical characteristics of the sunflower plant. Drought stress induced by extended irrigation intervals reduced leaf area and dry biomass, and the foliar application of MeJA significantly alleviated these conditions. Notably, applying a higher MeJA concentration (100 µmol) was more effective than a lower dose in enhancing biomass production, chlorophyll content, and water-use efficiency under limited water supply.

MeJA treatment also reduced oxidative damage, as evidenced by increased proline accumulation and relative water content, while decreasing solute leakage compared to untreated, drought-stressed controls. These improvements contributed to better photosynthetic performance and overall plant vigor under water deficit conditions.

Therefore, it is recommended to irrigate sunflower plants every 5 days and to apply MeJA concentrations at 100 µmol during the pre-flowering stage. This combination achieved the highest growth and physiological performance in this study and can be adopted as an effective strategy to improve drought tolerance and productivity of sunflower in arid and semi-arid environments.

Supplementary Materials

No Supplementary Materials.

Author Contributions

Author 1: methodology, writing—original draft preparation; Author 1 and 2: writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted following the protocol authorized by the Head of the Ethics Committee, University Al-Anbar, Iraq Republic.

Informed Consent Statement

No Informed Consent Statement.

Data Availability Statement

No Data Availability Statement.

Conflicts of Interest

The authors declare no conflict of interest.

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مقالة أصيلة

كفاءة رش تراكيز مثيلات الجاسمونيت ومراحل الرش في الصفات المورفولوجية والفسلجية تحت تاثير فترات ري مختلفة

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الخلاصة

أُجريَت تجربة حقلية على محصول زهرة الشمس الصنف فلامي في حقول كلية الزراعة – جامعة الأنبار خلال الموسم الصيفي، بهدف دراسة الاستجابة الفسيولوجية للمحصول بتراكيز مختلفة من مثيلات الجاسمونيت (٠، ٥٠، ١٠٠ ميكرومول) ومواعيد الرش (عند مرحلة ٦–١٠ اوراق وقبل التزهير)، وذلك تحت تأثير فترات ري متباينة (٥، ٩، و١٣ يومًا). نُفذت التجربة وفق تصميم القطاعات العشوائية الكاملة (R.C.B.D) بنظام الألواح المنشقة–المنشقة (Split–split plot) وبثلاث مكررات. أظهرت نتائج الدراسة أن فترة الري كل ٥ أيام حققت أفضل القيم لمؤشرات النمو والمؤشرات الفسيولوجية المدروسة، تلتها فترتا الري كل ٩ و١٣ يومًا بالتتابع. كما ساهمت معاملة الرش بجاسمونات المثيل في تعزيز نمو النبات، حيث حقق التركيز الأعلى (١٠٠ ميكرومول) أفضل النتائج، إذ أدى إلى زيادة المساحة الورقية بنسبة ٨.٠١٪، والوزن الجاف بنسبة ٢١.٦٩٪، ومعدل النمو النسبي بنسبة ١٤.٩٢٪، ومعدل نمو المحصول بنسبة ١٠.٦٥٪، ومعدل صافي التمثيل الضوئي بنسبة ١٨.٣٤٪، والكلوروفيل aبنسبة ٢٢.٠٢٪، والكلوروفيل b بنسبة ٢٤.١٧٪، ومحتوى الماء النسبي للأوراق بنسبة ٨.٦٥٪، والبرولين بنسبة ١٧.٣٤٪، في حين انخفض ارتشاح المركبات الذائبة بنسبة ٤٧.٩٣٪ مقارنة بالمعاملة القياسية (المقارنة). وبشكل عام، تحقق أفضل تداخل عند الجمع بين فاصل الإرواء لمدة خمسة أيام، والرش بتركيز ١٠٠ ميكرومول من مثيلات الجاسمونيت عند مرحلة الرش قبل التزهير، وبذا ادى الى اعطاء أداء أفضل في النمو والمؤشرات الفسيولوجية لنبات زهرة الشمس.

كلمات مفتاحية: تراكيز مثيل الجاسمونيت، فترات الري، مراحل الرش، الصفات الفسيولوجية، زهرة الشمس.

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