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Effect of Silicon and Abscisic Acid Spray on Growth, Yield and Quality of Sunflower under Different Irrigation Periods

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ABSTRACT

Background: During autumn season of 2022, a field experiment was conducted at College of Agricultural Engineering Sciences, University of Baghdad to investigate the effect of silicon and abscisic acid spraying on sunflowers under various water stress conditions on growth, yield and quality of sunflower in Calcareous Soil.

Methods: The experiment involved three levels of water stress, with irrigation scheduled every 2, 4 and 6 days. Additionally, three concentrations of silicon 0, 2 and 4 mg L^{-1} and three concentrations of abscisic acid 0, 0.5, 1 mg L^{-1} was considered. The experimental design employed a randomized complete block design (RCBD) with a split-split plot arrangement with three replicates.

Result: Results showed a significant effect of irrigation every 2 days exhibited superior performance, leading to peroxidase activity achieved 15.8 mg $protein^{-1}$, catalase activity of 10.98 mg $protein^{-1}$, abscisic acid concentration of 0.462 µg ml^{-1}, silicon concentrations of 0.283%. The application of 4 mg L^{-1} of silicon proved to be superior, resulting in peroxidase activity of 20.35 mg $protein^{-1}$, catalase activity of 18.58 mg $protein^{-1}$, abscisic acid concentration of 0.473 µg ml^{-1}, proline concentration of 12.46 µM g^{-1}, silicon concentrations of 0.246 % and seed yield of 6.064 Mg ha^{-1}. The use of 1 mg L^{-1} of abscisic acid achieved superiority, yielding peroxidase activity of 20.12 mg $protein^{-1}$, catalase activity of 19.05 mg $protein^{-1}$, abscisic acid of 0.508 µg ml^{-1}, proline concentration of 14 µM g^{-1}, silicon at 0.271 % and seed yield of 6.136 Mg ha^{-1} .

Key words: Abscisic acid, Drought stress, Silicon, Sunflower.

INTRODUCTION

Silicon is one of the most abundant nutrients in the Earth's crust and is found mainly in an inert state with a small portion in a dissolved state. Due to agricultural practices, large amounts of it have been removed from the soil (Shi *et al*., 2016; Sapre and Dinesh, 2016; Sinky, 2023; Truong *et al*., 2024). Although silicon is not considered essential nutrients for plants growth, some studies have shown that it constitutes 0.1-10% of dry matter production in some plants (Epstien, 2009; Verma *et al*., 2021 and Ebeed *et al*., 2023). The addition of silicon on the plants played a role in reducing the effect of water stress by reducing the production of reactive oxygen species (ROS) through the promotion of enzymatic antioxidants and converting hydrogen peroxide (H_2O_2) to water (Al-Aloosy *et al*., 2018; Saleem and Joody, 2019).

Abscisic acid is one of the essential plant hormones, serving not only as an internal signal within the plant but also as a stress hormone. It is plays a fundamental role in regulating plant growth by inhibiting the release of ethylene, which is considered a growth inhibitor. Its plays a crucial role during water stress and some researchers have referred to it as the "stress hormone" due to its rapid accumulation during stress conditions (Hussain *et al*., 2012; Majeed *et al*., 2019 and Hong-Tao *et al*., 2023). Al-Sahuki (2013) pointed out that ABA acts as an anti-transparent, generated in response to severe drought, leading to various changes in cell functions, such as stomata closure and that fully irrigated plants have their stomata wide open and any reduction in stomata openings leads to reduce water loss to a great extent (AL-Jeboori *et al*., 2017; Qadir *et al*., 2019 and Hussain *et al*., 2021). Studies indicate that improving plant tolerance to water stress, a process controlled by ABA, is important in reducing the rate of transpiration in leaves (Hussain *et al*., 2012 and Mustafa, 2017). ABA is the hormone that responds most to environmental stresses and is even involved in the direct response to water stress (Vlot *et al*., 2009 and Naser *et al*., 2020). Bakht *et al*. (2010) indicated that water stress during the vegetative growth stages leads to reducing the ability of cells to swell and elongate and reducing their size, thus reducing the leaf area depending on the level of water stress.

Water stress is a type of abiotic environmental stresses that occurs when the soil moisture content decreases due to insufficient rainfall or when water loss exceeds

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absorption through roots water uptake, leading to changes in the plants natural environment directly (a decrease in the water potential of the soil), Additionally, it results in physiological and biochemical changes in the plant's functions (Hashim and Ahmed, 2017; Abdulameer and Ahmed, 2019).

Sunflower crop (*Helianthus annuus L.*), part of the Asteraceae family, is one of the world's leading oil-producing crops. It has grown recently due to global oil shortages, making it the second-highest oil producer after soybeans due to its 12% oil content and high saturated fatty acids (>33%) which makes it a top choice among vegetable oils. Additionally, sunflower seeds are rich in protein (42-93%) (AL-Tameemi *et al*., 2019; Jasim and Al-Tameemi, 2023).

The aim is to study the effect of silicon and abscisic acid spraying on sunflowers under various water stress conditions on growth, yield and quality of sunflower in Calcareous Soil.

MATERIALS AND METHODS

A field experiment was conducted during the autumn season of 2022 in the fields of the College of Agricultural Engineering Sciences, University of Baghdad, Jadirya-Iraq in silty loam soil, was subjected to a Randomized Complete Block Design (RCBD) with three replications in a split-split plot arrangement. The main plots were assigned to different irrigation periods 2, 4 and 6 days symbolized as W_1, W_2 and W_3. Subplots were designated for the application of various concentrations of Silicon 0, 2 and 4 mg L^{-1}, symbolized as S_1, S_2 and S_3, while sub–sub plots contained treatments with different concentrations of abscisic acid 0, 0.5 and 1 mg L^{-1} symbolized as ABA_1, ABA_2 and ABA_3. Both abscisic acid and Silicon were applied at three distinct growth stages. Soil samples were randomly collected from the 0-30 cm depth, air-dried, crushed and sieved through 2 mm diameter sieve for subsequent physical, chemical and fertility analysis (Table 1). Sunflower seeds (Master) were sown in 2 × 2 m plots, fertilized with 160 kg N ha^{-1}, 40 kg P ha^{-1} and 70 kg K ha^{-1} using Urea (46% N), superphosphate (21% P) and potassium sulfate (41% K), respectively. Manual weeding was performed during the experiment.

RESULTS AND DISCUSION

Peroxidase activity

The results in Table (2) indicate that the third irrigation level W_3 significantly effect in peroxidase activity in the leaves

Table 1: Physical, Chemical and fertility properties of the Soil.

pH	EC	O.M	$CaCO_3$	CEC	N	P	K	Soil
	ds.m-1	%	%	c mol.c.kg1		mg kg^{-1} soil		texture
7.12	2.05	1.35	19.78	16.3	77.08	15.74	289.52	Si L

Table 2: Effect of silicon, abscisic acid spray and different irrigation periods on peroxidase activity (mg $protien^{-1}$).

		W_1	W_2	W_3	S * ABA
S_1	ABA_1	14.00	25.20	66.30	35.16
	ABA_2	17.50	24.90	34.70	25.70
	ABA_3	13.60	22.30	30.10	22.00
S_2	ABA_1	18.20	21.90	33.10	24.40
	ABA_2	14.60	22.80	30.70	22.70
	ABA_3	15.90	20.90	23.70	20.10
S_3	ABA_1	19.30	19.10	29.20	22.50
	ABA_2	15.40	17.80	27.80	20.30
	ABA_3	14.30	14.90	25.40	18.20
$LSD_{0.05}$		10.25			8.65
					Average
W*S	S_1	15.03	24.13	43.70	27.62
	S_2	16.23	21.86	29.16	22.35
	S_3	16.33	17.26	27.46	20.35
$LSD_{0.05}$		8.01			8.65
					Average
W* ABA	ABA_1	17.16	22.06	42.86	27.36
	ABA_2	15.83	21.83	31.06	22.91
	ABA_3	14.60	19.36	26.40	20.12
$LSD_{0.05}$		7.87			4.55
Average		15.8	21.0	33.4	
$LSD_{0.05}$		3.91			

achieved 33.4 mg protien^{-1} compared to W_1. It is also superior to concentration of silicon S_1 and achieved 27.62 mg protien^{-1} compared to S_3. The effect of spraying abscisic acid as ABA_1 achieved 27.36 mg protien^{-1} compared to ABA_3 which achieved 20.12 mg protien^{-1}. The triple interaction between water irrigation levels, silicon spraying and abscisic acid had a significant effect on peroxidase activity and achieved 66.3 mg protein^{-1} in $W_3S_1ABA_1$ compared to $W_1S_1ABA_3$.

Catalase activity

Rresults in Table (3) indicate that the third irrigation level W_3 significantly effect in catalase activity in the leaves achieved 30.26 mg protien^{-1} compared to W_1. Furthermore, it is also superior to concentration of silicon S_1 and achieved 22.57 mg protien^{-1} compared to S_3. The effect of spraying abscisic acid as ABA_1 achieved 23.13 mg protien^{-1} compared to ABA_3. The triple interaction between water irrigation levels, silicon spraying and abscisic acid had a significant effect on catalase activity in the leaves and achieved 36.90 mg protein^{-1} in $W_3S_1ABA_1$ compared to $W_1S_3ABA_3$.

Abscisic acid concentration in the leaves

Rresults in Table (4) indicate that the third irrigation level W_3 significantly effect in abscisic acid concentration achieved 0.607 µg ml^{-1} compared to W_1. Furthermore, it is also superior to concentration of silicon S_2 and gave 0.547 µg ml^{-1} compared to S_3. The effect of spraying abscisic acid as ABA_2 achieved 0.553 µg ml^{-1} compared to ABA_1. The triple interaction between water irrigation levels, silicon spraying and abscisic acid had a significant effect on abscisic acid in the leaves and achieved 0.803 µg ml^{-1} in $W_3S_1ABA_1$ compared to $W_2S_3ABA_2$.

Proline concentration in the leaves

Rresults in Table (5) indicate that the third irrigation level W_3 significantly effect in proline concentration in the leaves achieved 23.39 µM g^{-1} compared to W_1. Furthermore, it is also superior to concentration of silicon S_1, as it achieved 17.73 µM g^{-1} compared to S_3. The effect of spraying abscisic acid as ABA_1 achieved 17.37 µM g^{-1} compared to ABA_3. The triple interaction between water irrigation levels, silicon spraying and abscisic acid had a significant effect on proline concentration in the leaves and achieved 35.74 µM g^{-1} in $W_3S_1ABA_1$ compared to $W_2S_3ABA_2$.

Silicon concentrations in the leaves

Results in Table (6) indicate that the third irrigation level W_1 significantly effect in silicon concentration in the leaves achieved 0.283 % compared to W_3. Furthermore, it is also superior to concentration of silicon S_3, as it achieved 0.246 % compared to S_1. The effect of spraying abscisic acid as ABA_3 achieved 0.271 % compared to ABA_1. The triple interaction between water irrigation levels, silicon spraying and abscisic acid had a significant effect on silicon in the leaves and achieved 0.341 % in $W_1S_3ABA_3$ compared to $W_3S_1ABA_1$.

Seed yield

Rresults in Table (7) indicate that the third irrigation level W_1 significantly effect in seed yield achieved 6.760 Mg ha^{-1}

Table 3: Effect of silicon, abscisic acid spray and different irrigation periods on catalase activity (mg protien^{-1}).

		W_1	W_2	W_3	S * ABA
S_1	ABA_1	13.10	27.90	36.90	25.96
	ABA_2	7.60	20.80	33.20	20.53
	ABA_3	11.70	20.20	31.80	21.13
S_2	ABA_1	10.90	23.60	34.20	22.90
	ABA_2	12.50	18.70	29.80	20.33
	ABA_3	11.40	17.90	28.40	19.23
S_3	ABA_1	11.00	22.70	27.90	20.53
	ABA_2	13.20	17.10	25.30	18.53
	ABA_3	7.50	17.70	24.90	16.70
$LSD_{0.05}$		10.21			8.65
					Average
W*S	S_1	10.80	22.96	33.96	22.57
	S_2	11.60	20.06	30.80	20.82
	S_3	10.56	19.16	26.03	18.58
$LSD_{0.05}$		7.62			3.36
					Average
W* ABA	ABA_1	11.66	24.73	33.00	23.13
	ABA_2	11.10	18.86	29.43	19.79
	ABA_3	10.20	18.60	28.36	19.05
$LSD_{0.05}$		6.41			3.20
Average		10.98	20.73	30.26	
$LSD_{0.05}$		2.94			

compared to W_3. Furthermore, it is also superior to concentration of silicon S_3, as it achieved 6.064 Mg ha^{-1} compared to S_1. The effect of spraying abscisic acid as ABA_3 achieved 6.136 Mg ha^{-1} compared to ABA_1. The triple interaction between water irrigation levels, silicon spraying and abscisic acid had a significant effect on seed yield

Table 4: Effect of silicon, abscisic acid spray and different irrigation periods on Abscisic acid concentration (µg ml^{-1}).

		W_1	W_2	W_3	S * ABA
S_1	ABA_1	0.325	0.433	0.803	0.520
	ABA_2	0.440	0.601	0.549	0.530
	ABA_3	0.507	0.407	0.595	0.503
S_2	ABA_1	0.392	0.465	0.577	0.478
	ABA_2	0.463	0.612	0.784	0.619
	ABA_3	0.478	0.566	0.594	0.546
S_3	ABA_1	0.459	0.383	0.459	0.433
	ABA_2	0.520	0.334	0.677	0.510
	ABA_3	0.577	0.425	0.433	0.478
$LSD_{0.05}$		0.146			0.082
	Average				
W*S	S_1	0.424	0.480	0.649	0.517
	S_2	0.444	0.547	0.651	0.547
	S_3	0.518	0.380	0.523	0.473
$LSD_{0.05}$		0.072			0.036
					Average
W* ABA	ABA_1	0.392	0.427	0.613	0.477
	ABA_2	0.474	0.515	0.670	0.553
	ABA_3	0.520	0.466	0.540	0.508
$LSD_{0.05}$		0.089			0.053
Average		0.469	0.462	0.607	
$LSD_{0.05}$		0.064			

Table 5: Effect of silicon, abscisic acid spray and different irrigation periods on Proline concentration in the leaves (µM g^{-1}).

		W_1	W_2	W_3	S * ABA
S_1	ABA_1	16.38	12.92	35.74	21.68
	ABA_2	8.60	15.53	24.47	16.20
	ABA_3	8.73	18.52	18.72	15.32
S_2	ABA_1	8.40	14.02	31.69	18.03
	ABA_2	12.32	16.82	26.24	18.46
	ABA_3	13.70	10.25	22.22	15.39
S_3	ABA_1	12.01	7.62	17.56	12.39
	ABA_2	13.60	9.08	17.13	13.27
	ABA_3	10.39	8.10	16.75	11.74
$LSD_{0.05}$		7.97			4.17
					Average
W*S	S_1	11.23	15.65	17.56	17.73
	S_2	11.47	13.69	17.13	17.23
	S_3	12.00	8.26	16.75	12.46
$LSD_{0.05}$		5.71			2.36
					Average
W* ABA	ABA_1	12.26	11.52	28.33	17.37
	ABA_2	11.50	13.81	22.61	15.97
	ABA_3	10.49	12.29	19.23	14.00
$LSD_{0.05}$		5.34			2.94
Average		11.57	12.54	23.39	
$LSD_{0.05}$		3.46			

and achieved 7.442 Mg ha^{-1} in $W_1S_3ABA_3$ compared to $W_3S_1ABA_1$.

The results showed the effect of water stress, represented by irrigation every 6 days, on reduction of all growth indicators and an increase in the efficiency of antioxidant enzymes and some non-enzymatic antioxidants. When plants are exposed to water stress, the activity of peroxidase and catalase enzymes increases in response to suppressing the harmful effect of this stress (Ulusu *et al*., 2022; Orejuela-Romero *et al*., 2023 and Al-Rubaie and Al-Jubouri, 2023) Water stress stimulates oxidative stress, leading to an increase in free radicals such as super oxides (O^{-2}) and hydrogen peroxide (H_2O_2). These radicals are known as reactive oxygen species (ROS), causing adverse effects on membrane lipids, proteins, DNA and RNA, resulting in membrane damage, disturbance in cellular metabolic processes and a decrease in chlorophyll content (Abu Jadallah, 2018; Dhahi and Baktash, 2018 and Chowdary *et al*., 2021).

Suppression of reactive oxygen species (ROS) in plants occurs through various mechanisms, including enzymatic and non-enzymatic processes. The enzymatic mechanism for inhibit ROS in plants includes enzymes such as superoxide dismutase (SOD), catalase and peroxidase (POD). These enzymes remove the toxicity of free radicals and high regulation of their activity is necessary to keep free radicals under control (Al-Fadhly *et al*., 2019; El-Fahdawi *et al*., 2020;Rudenko *et al*., 2023; Riwad and Alag, 2023). Furthermore, plant exposure to water stress contributes to an increase the proline content, acting as a protective measure against these conditions. The reason for the increase in the proline content is attributed to its limited involvement in protein formation on the one hand, or from the increase in protein catabolism and its conversion into amino acids, including proline acid. On the other hand, water deficit increased the activity of the enzyme Pyrroline-5-Carboxylate Reeducates (P5CR), which reduces Pyrroline-5-Carboxyleic acid (P5C) to proline acid (Mahmood *et al*., 2019; Mahmood *et al*., 2020; Wang *et al*., 2022 and Juma *et al*., 2024).

The increase in abscisic acid (ABA) concentration is due to a direct relationship between leaf ABA content and water deficiency as confirmed by Al-Fatlwai (2013); Cao *et al*. (2020) and Hwaidi (2023), who indicated that abscisic acid is a plant hormone formed in response to various environmental stresses and acts to close plant stomata as an indicator of increased external stresses, especially drought on the plant. Silicon role in alleviating drought stress, enhancing plant growth and development, increasing photosynthesis activity, reducing transpiration, as well as improving plant growth, water and nutrients absorption, carbon metabolism and stomata regulation (Mahmood *et al*., 2020 and Rawaa and Wafaa, 2024). Additionally, silicon contributes to improving scavenging process and getting rid of free radicals by regulating the effectiveness of antioxidant enzymes (Cooke and Carey, 2023; Vieira-Filho and Monteiro, 2022; Mir *et al*., 2022; Irfan *et al*., 2023 and Ahmed and Al-Tameemi, 2023).

The results also showed the role of spraying with abscisic acid in resisting water stress through its role in increasing the activity of antioxidant enzymes such as

Table 6: Effect of silicon, abscisic acid spray and different irrigation periods on Silicon concentrations in the leaves.

		W_1	W_2	W_3	S * ABA
S_1	ABA_1	0.157	0.196	0.134	0.162
	ABA_2	0.297	0.191	0.278	0.255
	ABA_3	0.337	0.282	0.197	0.272
S_2	ABA_1	0.231	0.243	0.143	0.205
	ABA_2	0.298	0.268	0.203	0.256
	ABA_3	0.326	0.227	0.223	0.259
S_3	ABA_1	0.225	0.203	0.120	0.183
	ABA_2	0.333	0.251	0.228	0.271
	ABA_3	0.341	0.262	0.247	0.283
$LSD_{0.05}$		0.091			0.052
					Average
W*S	S_1	0.264	0.223	0.203	0.230
	S_2	0.285	0.246	0.189	0.240
	S_3	0.300	0.239	0.198	0.246
$LSD_{0.05}$		0.044			0.024
					Average
W* ABA	ABA_1	0.204	0.214	0.132	0.184
	ABA_2	0.309	0.237	0.236	0.261
	ABA_3	0.335	0.257	0.222	0.271
$LSD_{0.05}$		0.049	0.033		
Average	0.283	0.236	0.197		
$LSD_{0.05}$		0.036			

Table 7: Effect of silicon and abscisic acid spray and different irrigation periods on Seed yield (Mg ha^{-1}).

		W_1	W_2	W_3	S * ABA
S_1	ABA_1	6.427	5.409	4.031	5.289
	ABA_2	7.013	5.796	4.536	5.781
	ABA_3	7.371	5.867	4.959	6.065
S_2	ABA_1	6.261	5.545	4.785	5.530
	ABA_2	7.118	5.981	5.069	6.056
	ABA_3	6.583	5.837	5.236	5.885
S_3	ABA_1	6.457	5.623	5.304	5.794
	ABA_2	6.176	6.014	5.641	5.943
	ABA_3	7.442	6.128	5.802	6.457
$LSD_{0.05}$		0.830			0.613
					Average
W*S	S_1	6.937	5.690	4.508	5.711
	S_2	6.654	5.787	5.030	5.823
	S_3	6.691	5.921	5.582	6.064
$LSD_{0.05}$		0.496			0.425
					Average
W* ABA	ABA_1	6.381	5.525	4.706	5.538
	ABA_2	6.769	5.930	5.082	5.927
	ABA_3	7.132	5.944	5.332	6.136
$LSD_{0.05}$		0.482			0.363
Average		6.760	5.800	5.040	
$LSD_{0.05}$		0.352			

peroxidase and catalase, reducing the transpiration rate through partial stomata closure, increasing root growth rate and thereby maintaining plant water content, These mechanisms contributes to reducing the effect of water stress, enhancing seed yield and improving water use efficiency (Aslam *et al*., 2022; Li *et al*., 2022; Jiang *et al*., 2022 and Al-Mashhadany and Al-Amery, 2023).

CONCLUSION

The beneficial effects of silicon and abscisic acid Spray on growth, yield and quality of sunflower under different Irrigation Periods in calcareous soil. Irrigation every 2 days significantly enhanced physiological parameters and seed yield. The highest concentrations of silicon 4 mg L^{-1} and abscisic acid at 1 mg L^{-1} resulted in superior peroxidase and catalase activities, abscisic acid and proline in the leaves, increased silicon and improved seed yield.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERECNCES

Abdulameer, O.Q. and Ahmed S.A. (2019). Role of humic acid in improving growth characters of corn under water stress. Iraqi Journal of Agricultural Sciences. 50(1): 420-430.

Abu Jadallah, J.M. (2018). Molecular plant physiology and biology during water stress. Faculty of Science-Damietta University. Egypt. p. 229.

Ahmed, F.W. and Al-Tameemi, A.J.H. (2023). Effect of irrigation with acidified water and phosphorous, iron and zinc on nutrients concentration, growth and yield of cabbage. IOP Conf. Series: Earth and Environmental Science. 1262: 082068. doi: 10.1088/1755-1315/1262/8/082068.

Al-Aloosy, Y.A.M., Al-Tameemi, A.J.H. and Salman, A.H. (2018). The effect of soil acidification in the availability of phosphor on growth of Cucumber *Cucumis sativus* L. crop. International Journal of Agricultural and Statistical Sciences. 14(1): 287-292.

Al-Fadhly, Jawad T.M., Ahmed, F.W. and Abd, W.M. (2019). Effect of spraying with zinc and manganese at different stage of potato growth on quality of potato tuber (*Solanum tuberosum* L.) desiree class: As a role of friendly biochemical health. Biochem. Cell. Arch. 19(2): 3955-3959.

AL-Jeboori, K.D., AL-Mharib M.Z.K., Hamdan, A.Q. and Mahmood, A.H. (2017). Effect of irrigation intervals and foliar of salicylic acid on growth and yield of Potato. Iraqi Journal of Agricultural Sciences. 48(1): 242-247.

Al-Mashhadany, A.H. and Al-Amery N.J. (2023). Enhancing vegetative growth by adding phosphorus, silicon and citric acid to pepper plants pultivated in plastic greenhouses. IOP Conference Series: Earth and Environmental Science. 1262: 042068. doi: 10.1088/1755-1315/1262/4/042068.

Al-Rubaie, A.H.S. and Kadhim, D.H.A. (2023). Effect of tocopherol, trehalose and soil improvement in water productivity and industrial potatoes under water stress. Iraqi Journal of Agricultural Sciences. 54(4): 979-995.

Al-Sahuki, M.M. (2013). Breeding crops to withstand abiotic stress- a molecular and epigenetic perspective. Number of pages: 244.

AL-Tameemi, A.J.H., Al-Aloosy, Y.A.M. and Jumaa, S.S. (2019). Nano fertilizers and optimum crop productivity: A review. Plant Archives. 19: 552-554.

Aslam, M.M., Muhammad W., Bello H.J., Eyalira J.O., Zuliang, L., Hafiz, S.A.S., Wei, Y.W.X. and Qian, Z. (2022). Mechanisms of abscisic acid-mediated drought stress responses in plants. Int. J. Mol. Sci. 23(3): 1084. doi: 10.3390/ijms 23031084.

Bakht, J.M., Shafi. M., Yousaf, L.R. and Khan, M. (2010). Effect of irrigation on physiology and yield of Sunflower hybrids. Pak. J. Bot. 42(2): 1317-1326.

Cao, X., Longlong, W., Meiyan, W., Chunquan, Z., Qianyu, J. and Junhua, Z. (2020). Abscisic acid mediated proline biosynthesis and antioxidant ability in roots of two different rice genotypes under hypoxic stress. BMC Plant Biology. 20(198): 1-14.

Chowdary, B.Y., Lakshmi, P., Reddy, S.N., Eshwari, K.B., Meena, H.P. and Srikanth, B. (2021). Effect of water stress on physiological traits of sunflower (*Helianthus annuus* L.) restorer lines. J. Oilseeds Res. 38(1): 54-58.

Cooke, J. and Joanna, C.C. (2023). Stress alters the role of silicon in controlling plant water movement. Functional Ecology. 37: 2985-2999.

Dhahi, A.M. and Baktash, F.Y. (2018). Impact of moisture depletion percentages on some growth characters and yield for selected genotypes of bread wheat. Iraqi Journal of Agricultural Sciences. 49(2): 160-270.

Ebeed, H.T., Nemat, M.H., Hanan, S.A. (2023). Silicon-mediated improvement of drought tolerance in two wheat genotypes. Egypt. J. Bot. 63(2): 563-580.

El-Fahdawi, W.A.T., Firas, W., Ahmed and Cheyed, S.H. (2020). Effect of agricultural sulfur on availability of NPK in soil, growth and yield of corn (*Zea mays* L.). Indian Journal of Ecology (2020) 47 Special Issue. 12: 200-205.

Hashim, E.K. and Ahmed, S.A. (2017). Of some field traits of wheat to aba under effect of water stress response. Iraqi Journal of Agricultural Sciences. 48(4): 957-970.

Hong-Tao, X., Wan, L., Jia, L., Ning, H., Xue-Yang, W., Bo, L., Hong-Chang, X., De-Ming, W. (2023). Effect of exogenous abscisic acid (ABA), a potential growth regulator on physiological response to chilling stress of adzuki bean (*Vigna angularis*) at flowering stage. Legume Research. 46(12): 1604-1609. doi: 10.18805/LRF-748.

Hussain, S., Ali, A., Ibrahim, M., Saleem, M.F., Alias, M.A. and Haji, A.B. (2012). Exogenous application of abscisic acid for drought tolerance in sunflower (*Helianthus annuus* L.): A review. J. Anim. Plant Sci. 22(3): 806-826.

Hussain, S., Ma, B.L., Saleem, M.F., Shakeel, A.A., Saeed, A. and Iqbal, J. (2012). Abscisic acid spray on sunflower acts differently under drought and irrigation conditions. Agronomy Journal. 104(3): 561-568.

Hussain, S., Shahid, F., Muhammad, A.B., Sagheer, A., Muhammad, J., Muhammad, M.M., Arif, H. and Muhammad, N.M. (2021). Abscisic acid (ABA) mitigates drought stress in sunflower by enhancing water relations and osmotic adjustments. Pure Appl. Biol. 10(1): 182-193.

Hwaidi, M.I. (2023). Effect of sowing date and abscisic acid on sunflower growth, seed yield and germination. Kirkuk University Journal for Agricultural Sciences. 14(1): 106-116.

Irfan, M., Muhammad, A.M., Hafeez, U.R., Wajid, M. and Nadeem, S. (2023). Silicon nutrition in plants under water-deficit conditions: Overview and prospects. Wate. 15. 739. https://doi.org/10.3390/w15040739.

Jasim, D.J., Al-Tameemi, A.J.H. (2023) Effect of the agricultural sulfur levels and thiobacillus bacteria on the availability of some nutrients and broccoli productivity. Earth and Environmental Science. 1262(8): 082055. doi: 10.1088/1755-1315/1262/8/082055.

Jiang, Z., Hengguang, Z., Hanyu, Z., Yuzhao, T., Changzhuang, L., Jiaqi, L., Fuqiang, Y. and Ming, L. (2022). Exogenous ABA enhances the antioxidant defense system of maize by regulating the ASA-GSH cycle under droug. Sustainability. 14. 3071.

Juma, S.S., Ahmed, F.W. and Alsalman, A.H. (2024). Effect of humic acid, calcium and poultry waste on growth and yield of broccoli effect of humic acid, calcium and poultry waste on growth and yield of broccoli. Earth and Environmental Science. 1302012119. doi: 10.1088/1755-1315/1302/1/012119.

Li, S., Sha, L., Qiong, Z., Meixiang, C., Min, Z., Nanyang, L., Suna, W., Ruigang, W., Lin, Z., Yunpeng, C. and Lihu, W. (2022). The interaction of ABA and ROS in plant growth and stress resistances. Plant Science. Pp 1-16.

Mahmood, Y.A., Firas, W.A., Sinan, S.J., Al-Arazah, A.A. (2019). Effect of solid and liquid organic fertilizer and spray with humic acid on growth, yield of Cauliflower and nutrient uptake of nitrogen, phosphorus and potassium. Plant Archives. 19(2): 1504-1509.

Mahmood, Y.A., Iman, Q.M. and Firas, W.A. (2020). Effect of organic fertilizer and foliar application with garlic extract whey and bio fertilizer of bread yeast in availability of NPK in soil and plant, growth and yield of tomato (*Lycopersicon esculentum* Mill). Plant Archives. 20(1): 151-158.

Mahmood, Y.A., Iman, Q.M., Firas, W.A. and Kusay, A.W. (2020). Effect of organic, mineral fertilizers and foliar application of humic acid on growth and yield of corn (*Zea mays* L.). Indian Journal of Ecology. 47(10): 39-44.

Majeed, B.H., Mohammed, M.M. and Ahmed, H.A. (2019). Influence of foliar application of ascorbic acid and atonik on growth and yield of potato. Research on Crops. 20: S58-S60.

Mir, R.A., Basharat, A.B., Henan, Y., Sheikh, T.I., Ali, R., Masood, A.R., Sidra, C., Mohammed, A., Parvaze, A.S. and Sajad, M.Z. (2022). Multidimensional role of silicon to activate resilient plant growth and to mitigate abiotic stress. Frontiers in Plant Science. 13. 819658.

Mustafa, S.B.I. (2017). The biological effectiveness of gibberellic acid seeds soaking and foliar to abscisic acid in the growth, anise oil yield and its chemical content. Iraqi Journal of Agricultural Sciences. 48(5): 1175-1364.

Naser, K.M., Al-Tameemi, A.J.H. and Hayder, A.B. (2020). Effect of applying selenium element and ascorbic acid on reducing the harmful effect of environmental stress on wheat plants irrigated by water contaminated with lead and cadmium. Plant Archives. 20(1): 1805-1811.

Orejuela-Romero, J.A., Juan, G.C., Pablo, D.C. and Ana, X.S. (2023). Effect of deficit irrigation on *Helianthus annuus* L. plants in containers. Rev. Fac. Agron. (LUZ). 40(2): e234012.

Qadir, S.A., Khursheed, M.Q., Rashid, T.S. and Awla, H.K. (2019). Abscisic acid accumulation and physiological indices in responses to drought stress in wheat genotypes. Iraqi Journal of Agricultural Sciences. 50(2): 705-712.

Rawaa, G.A. and Wafaa, A.H. (2024). Effect of organic fertilizers and nutrients on anatomical traits of red beetroots. Iraqi Journal of Agricultural Sciences. 55(Special Issue). pp 151-161.

Riwad, M.T. and Alag, M.K. (2023). Role of Nano and metallic boron foliar nutrition on water stress reducing in sweet corn yield and its components. Iraqi Journal of Agricultural Sciences. 54(5): 1421- 1432.

Rudenko, N.N., Daria, V.V., Tatiana, V.M. and Maria, M.B. (2023). Antioxidants of non-enzymatic nature: their function in higher plant cells and the ways of boosting their biosynthesis. Antioxidants. 12. 2014.

Saleem, Q.T.S. and Ahmed, T.J. (2019). Effect of silicon, calcium and boron on apple leaf minerals content. Iraqi Journal of Agricultural Sciences. 50(1): 192-202.

Sapre, Sarang, S. and Vakharia, D.N. (2016). Role of silicon under water deficit stress in wheat: (Biochemical perspective): A review. Agricultural Reviews. 37(2): 109-116. doi: 10.18805/ar.v37i2.10736.

Shi, Y., Yi, Z., Weihua, H., Ru, F., Yanhong, H., Jia, G. and Haijun, G. (2016). Silicon enhances water stress tolerance by improving root hydraulic conductance in *Solanum lycopersicum* L. Plant Science. 22(2): 1-15.

Sinky, A.D., Sapna, S., Meenakshi, Kumar, V., Soni, A. and Sharma, K.D. (2023). Impact of silicon application on physiochemical traits of *Vigna radiata* exposed to salinity stress. Indian Journal of Agricultural Research. 58(1): 113-119. doi: 10.18805/IJARe.A-6150.

Truong, Hoa, T.D., Tran, T.D., Do, D.T., Trinh, T.S., Hoang, T.T.H. (2024). Effect of silicon based fertilizer and biochar from crop residues on dry matter accumulation and si uptake by rice crop in central Vietnam. Indian Journal of Agricultural Research. 58(4): 588-594. doi: 10.18805/IJARe.AF-844.

Ulusu, F., Kader, T. and Yakup, U. (2022). Antioxidant responses to drought stress in pennyroyal (*Mentha pulegium* L.). Journal of Scientific Reports-A. 51: 26-48.

Verma, K.K., Xiu-Peng, S., Bo, L., Dao-Jun, G., Munna, S., Vishnu, D.R., Rajesh, K.S., Pratiksha, S., Anjney, S., Mukesh, K.M., Gan, L.C., Yang-Rui, L. (2021). Silicon induced drought tolerance in crop plants: Physiological adaptation strategies. Silicon. 14: 2473-2487.

Vieira-Filho, L.O. and Francisco, A.M. (2022). Silicon improves photosynthetic activity and induces antioxidant enzyme activity in tanzania guinea grass under copper toxicity. Plant Stress. 3. 100045. https://doi.org/10.1016/j.stress.2021.100045.

Vlot, A.C., Dempsey, D.M. and Klessig, D.F. (2009). Salicylic acid multifaceted hormone to combat disease. Annual Review of Phytopathology. 47: 177-206.

Wang, Z., Yongchao, Y., Vivek, Y., Wei, Z. and Yaping, H. (2022). Drought-induced proline is mainly synthesized in leaves and transported to roots in watermelon under water deficit. Horticultural Plant Journal. 8(5): 615-626.