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ROLE OF ABSCISIC ACID AND POTASSIUM IN BROAD BEAN GROWTH UNDER WATER STRESS CONDITIONS

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SUMMARY

The experiment happened at Al-Mussaib Technical College, Al-Furat Al-Awsat Technical University, to know the effect of ABA acid and potassium on the growth of broad bean (*Vicia faba* L) plants under water stress conditions (0 and 1000 mg k^{-1}) while the third factor was an ABA acid at the concentration of 0.2 mM. The results were as follows: All studied traits decreased under conditions of water stress (plant height, leaf number, leaf area, total soluble carbohydrates [TSC], activity of superoxide dismutase [SOD], and catalase of broad beans) with recorded values of 41 cm, 5.67 leaf $plant^{-1}$, 60.57 cm^2, 11.82 (mg g^{-1} DW), 155.01 units mg^{-1} protein min^{-1}, and 138.59 mg^{-1} protein min^{-1}, respectively. The obtained triple interaction treatment was also at 25 ds m^{-1} + 1000 mg l^{-1} + 0 ABA, giving the highest values for all studied traits. ABA and potassium apart and together boosted proline, TSC, SOD, and CAT, raising plant height, leaf number, and area. The combined treatment improved plant growth and antioxidant systems, reducing the suppressive effect of water deprivation. ABA and potassium-treated plants showed greater TSC.

Keywords: *Vicia faba* L., growth regulators, nutrient elements, water stress, growth traits

Key findings: The results revealed applying ABA, potassium, and their interaction improved all growth traits by increasing proline content, total soluble carbohydrates, CAT, and SOD. The findings of this study indicated that ABA and potassium together assisted the plant in regaining the altered physiological features caused by water stress.

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INTRODUCTION

One of the main winter legume crops, the broad bean (*Vicia faba* L.), distinct for its high protein content, makes it a source of green protein and an essential component of many people's diets, particularly those with low incomes (Abed *et al.*, 2022; Jaafar *et al.*, 2022). Moreover, allowing the soil to fix nitrogen enhances the quality of fertile soil.

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In addition to its vital effect resulting from the activity of rhizobial bacteria (Kandil, 2007), marked restrictions on the growth and development of crops come from a variety of biotic and abiotic stresses, such as fungi, bacterial infections, salinity, drought, flooding, toxicity with heavy metals, and others, limiting agricultural crop production due to oxidative damage to cells and tissues resulting from reactive oxygen species (ROS) overproduction (Azhar *et al*., 2011; Moosavi, 2012; Huang *et al*., 2019).

Water stress disrupts photosynthesis, carbohydrates, respiration, translocation, ion absorption, and all growth stimulants (Farooq *et al*., 2008, AL-Fatlawi *et al*., 2022, Farhood *et al*., 2022). Changes in Ribulose 1, 5-bisphosphate carboxylase, and stomatal conductance decrease photosynthesis (Zhao *et al*., 2020). Scientists must improve plant water utilization or use drought-resistant substances like Abscisic Acid (ABA), potassium, and others to reduce the adverse effects of water stress. Abscisic Acid (ABA), a phytohormone, helps plants communicate under water stress (Moussa and Abdel-Aziz, 2008; Moosavi, 2012; Sah *et al*., 2016).

Maintaining steady water levels during floods and droughts is ABA's primary responsibility. Salazar *et al*., (2015) say that ABA levels rapidly rise in wet plant roots and leaves and then drop again. Several physiological and biological processes, as well as the growth and maintenance of plants, need potassium. Min *et al*., (2013) and Chantal *et al*., (2019) say that K+ helps plants deal with water stress by keeping cell membranes, aquaporins, water uptake, osmotic adaptation, stomatal control, and ROS detoxification healthy. The goal of this study was to find out if misting potassium and ABA could help people who were dehydrated..

MATERIALS AND METHODS

In the Babil Governorate, an experiment was set up at Al-Musayyib College, Al-Furat Al-Awsat Technical University, during the growing season of 2021–2022. The goal was to learn more about what happens to bean plants when they are severely water stressed and are sprayed with potassium and abscisic. Where the test took place: between 33° and 32° north latitude and 45° to 44° east longitude. A split plot with three copies and a randomized complete block design (RCBD) were used in the study. Applying three water stress treatments to the main plots comprised 100% field capacity irrigation (I1), 50% field capacity irrigation (I2), and 25% field capacity irrigation (I3). In the subplots, foliar spraying with abscisic had two treatments (0 and 0.25 mM), while sub-subplots included two treatments of potassium spraying (0 and 1000 mg L^{-1}). Potassium spraying on leaves occurred during the branching period, followed by an ABA spraying.

Studied traits

The measurement of plant height followed one month after the spraying. It involved using a ruler to measure the height from the soil surface to the apex of the main branch. The quantification of the number of active plant leaves on the main plant continued at a time interval of one month following the spray application. For leaf area (cm^2), employing the disc method (8) helped compute the leaf area of new leaves, with the estimation of leaf area conducted one month after applying the spray. Determining total soluble carbohydrates (TSC) (mg g^{-1}) engaged the methodology proposed by Yemm and Willis (1954). For proline content (μg g^{-1}) estimation utilized the approach in Bates *et al*. (1973) study. The SOD activity (units mg^{-1} protein min^{-1}) applied the methodology outlined by Giannopolitis and Ries (1977). The catalase activity assessment (units mg^{-1} protein min^{-1}) followed the technique outlined by Aebi (1984). The MDA under water stress (nmol g^{-1} FW) concentration determination used the method described by Heath and Packer (1968). The process of creating homogenates, starting with leaf weighing, had the following steps: 100% trichloroacetic acid and 0.65% 2-thiobarbituric acid made up these homogenates. The homogenates underwent heating for 60 min at 95 °C. After heating, homogenates proceeded to cool at an ambient temperature before being centrifuged for 10 min at a force equal to 10,000 times the acceleration caused by gravity (10,000 × g). Using a reagent blank as a reference, measuring the absorbance of the supernatant had wavelengths of 532 and 600 nm.

Statistical analysis

The experiment involved RCBD and a split plot with three replicates. Evaluating the averages used the application of Genestat's least significant difference (LSD) test (Kadem and Abed, 2018).

RESULTS AND DISCUSSION

Plant height

The irrigation at 50% and 25% of the field capacity caused a significant decrease in plant height, as they gave averages of 50 and 41 cm, respectively, and the 100% irrigation treatment of the field capacity gave the highest plant height average at 60 cm (Table 1). The decrease in plant height as a result of less irrigation may be due to the lack of water in the chloroplast and the relative water content, causing disturbances in the enzymatic system, which inhibits the process of photosynthesis and stops the growth division and development (Kasim *et al.,* 2017**)**.

The treatment spray with abscisic acid (0.2 mM) gave an average of 49 cm; however, the control treatment showed an average of 51 cm. The reason for the decrease in plant height was that spraying with abscisic could cause a decline in division and, thus, plant height decreases (Abdelaal, 2015**)**.

The potassium (1000 mg L^{-1}) spray treatment produced an average of 55 cm, with the control treatment only an average of 46 cm. The role of potassium in promoting cell division and elongation, particularly meristematic cells in developing tips of stems, could be responsible for the rise in plant height (Alhasany *et al*., 2021).

The interaction between the control treatment of spraying with abscisic plus the treatment of potassium spraying (1000 mg l^{-1}) under the irrigation effect at 100% of the field capacity gave the highest value (64.01 cm), while the lowest was 34.34 cm, in the interaction between spraying treatment with abscisic (0.2 mM) with a control treatment of potassium under the effect of 25% field capacity. The absence of water in the chloroplast and the relative water content, which disrupts the enzymatic system, limits photosynthesis, and halts cell division and

Table *1*. Effect of ABA and K on plant height under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	60.23	56.02	58.12
	1000	64.01	58.08	61.04
50	0	48.04	38.11	43
	1000	54.44	57.21	51
25	0	35.34	34.34	35
	1000	42.23	52.36	47
$LSD_{0.05}$		2.07		1.63
				TW Mean
TW * ABA	100	62	57	60
	50	51	48	50
	25	39	43	41
$LSD_{0.05}$		1.63		1.07
				K Mean
K*ABA	0	48	43	46
	1000	53	57	55
$LSD_{0.05}$		1.23		0.98
ABA		51	49	
$LSD_{0.05}$		0.98		

Table *2*. Effect of ABA and K on leaf number under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	12.54	9.89	11.23
	1000	17.43	17.54	17.49
50	0	7.65	5.42	6.49
	1000	9.34	10.21	9.78
25	0	5.48	3.78	4.63
	1000	5.89	7.54	6.72
LSD$_{0.05}$		3.92		3.02
				TW Mean
TW *ABA	100	14.98	13.72	14.35
	50	8.54	7.82	8.18
	25	5.67	5.66	5.67
LSD$_{0.05}$		3.02		2.13
				K Mean
K*ABA	0	8.57	6.36	7.47
	1000	10.89	11.76	11.33
LSD$_{0.05}$		2.2.73		1.73
ABA		9.72	9.06	
LSD$_{0.05}$		0.63		

growth, may have caused the decrease in plant height. In addition to the abscisic acid as an inhibitor, potassium can effectively stimulate cell proliferation and elongation, particularly in meristematic cells at the growing tips of stems (Siddiqui *et al*., 2012, 2013).

Leaves per plant

Table 2 provides findings demonstrating notable variations among the water stress treatments. Irrigation at 50% and 25% of the field capacity resulted in averages of 5.67 and 2.13 leaves per plant, respectively, causing a significant reduction in the number of leaves per plant. At 100% of the field capacity, the applied treatment produced the highest average number of leaves, 14.35 per plant. The plant's exposure to a lack of water may have resulted in inadequate metabolic products to finish the production of the maximum number of leaves, which is why the number of leaves has decreased. The outcomes matched those of Ammar *et al.* (2015).

The treatment spray with abscisic (0.2 mM) gave an average of 9.06 leaf plant^{-1}, and the control treatment gave an average of 9.72. The lower leaves wilt and fall due to lack of water because the fall of leaves is a defensive method that allows the plant to inhibit transpiration while exposed to water stress, and the more exposure of the plant to water stress, the more leaves fall as a result of the increase in the abscisic acid concentration, which rises with escalating exposure of the plant to water stress. These results were similar to Abdelaal (2015).

The potassium spraying treatment (1000 mg L^{-1}) produced an average of 11.33 leaf plant^{-1}, while the control treatment (potassium 0) gave an average of 6.36 leaf plant^{-1}. The increase in the number of leaves can be due to an upsurge in the plant’s efficiency to intercept and absorb the maximum sunlight, thus increasing the output of photosynthesis and the plant’s ability to build carbohydrates crucial to carry out all its vital activities. These results were consistent with the findings of Laftta and Habib (2021).

The highest interaction was in the control treatment spray with absinthe (0.2 mM) plus the treatment of spraying with potassium at 1000 mg L^{-1}, under the irrigation effect at 100% of the field capacity, providing an average of 17.54 leaf plant^{-1}. Inversely, the minimum interaction produced 3.78 leaf plant^{-1} in the 0.2 abscisic spraying treatment with the control treatment of potassium spraying under 25% field capacity. Potassium's role in regulating stomatal opening and closing increased photosynthesis efficiency, which, in turn, enhanced the plant's ability to assimilate dry matter (Ouzounidou *et al*., 2014), leading to more leaves on the plant.

Table *3*. Effect of ABA and K on leaf area under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	97.05	75.45	86.25
	1000	82.89	96.67	89.78
50	0	66.78	54.89	60.84
	1000	78.54	84.98	81.76
25	0	56.79	59.76	58.28
	1000	60.07	65.65	62.86
$LSD_{0.05}$		8.07		7.32
				TW Mean
TW *ABA	100	89.97	86.11	88.04
	50	77.66	69.94	73.80
	25	58.43	62.71	60.57
$LSD_{0.05}$		7.32		5.63
				K Mean
K*ABA	0	73.54	63.37	68.46
	1000	73.83	82.43	78.13
$LSD_{0.05}$		5.42		4.04
ABA		73.69	72.90	
$LSD_{0.05}$		0.71		

Leaf area

The results in Table 3 showed a significant difference between the water stress treatments, as irrigation at 50% and 25% of the field capacity significantly decreased leaf area, with averages of 73.80 and 60.57 cm^2, respectively, and the treatment at the field capacity of 100% gave the highest average leaf area (88.04 cm^2). When a plant is under stress from a lack of water, its relative water content drops, slowing its vegetative parts' growth by stifling cell division and expansion. In turn, it slows the rate of photosynthesis, causing leaf area to decrease. Abid *et al*. (2017) reported the same outcomes.

Table 3 results showed that spraying with abscisic acid caused a significant decrease in leaf area. Spraying with abscisic acid at 0.2 mM gave an average of 72.90 cm^2; however, the control treatment gave an average of 73.69 cm^2. The decrease in the plant's leaf area may refer to the role of abscisic acid in inhibiting vital processes with the plant's exposure to water stress. Among these processes is transpiration as a result of its role in the process of closing the stomata, and thus, the representation of CO_2 decreases, causing an imbalance in the structural processes and, then, lowering the accumulation of dry matter, which is harmful to the leaf area (Karuppanapandian *et al.,* 2017).

Spraying with potassium significantly affected leaf area (Table 3). The potassium spray treatment at 1000 mg l^{-1} gave an average of 78.13 cm^2, with the control treatment only an average of 68.46 cm^2. A reason for this is the role of potassium in increasing the division and elongation of plant cells, including leaf cells. These results were consistent with Ding *et al.* (2021).

More results showed a significant interaction between the study factors (Table 3), as the highest interaction was in the control treatment sprayed with abscisic acid (0.2 mM), with an average of 97.05 cm^2. Meanwhile, the control treatment with potassium under the irrigation effect at 100% of the field capacity produced the lowest interaction of all spraying treatments. Abscisic acid (0.2) with the control treatment of spraying with potassium under 50% of the field capacity resulted in an average of 54.89 cm^2***.*** The increase in leaf area at 100% of field capacity is due to the plant obtaining sufficient amounts of water, favorably impacting the plant's efficiency in accumulating dry matter (Abd El-Mageed *et al.,* 2021).

Table 4. Effect of ABA and K on TSC under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	11.89	11.78	11.84
	1000	19.67	13.99	16.83
50	0	10.76	10.06	10.41
	1000	17.75	17.67	17.72
25	0	8.95	9.64	10.59
	1000	13.78	14.89	14.34
LSD$_{0.05}$		2.32		1.82
				TW Mean
TW *ABA	100	15.78	12.89	14.34
	50	14.26	13.87	14.06
	25	11.37	12.27	11.82
LSD$_{0.05}$		1.82		1.03
				K Mean
K*ABA	0	10.53	10.49	10.51
	1000	17.10	15.52	16.31
LSD$_{0.05}$		1.08		0.74
ABA		13.82	13.01	
LSD$_{0.05}$		0.74		

Total soluble carbohydrates (TSC) (mg g^{-1})

The results presented in Table 4 demonstrate the significant differences between the water stress treatments. Specifically, irrigation at 25% of field capacity significantly decreased the total concentration of carbohydrates, with an average of 11.82 mg g^{-1}. Irrigation at 100% of field capacity produced the highest average, reaching 14.34 mg g^{-1}; however, irrigation at 50% of field capacity did not significantly differ from irrigation at 100% of field capacity, with an average of 14.06 mg of carbohydrates. The plant's exposure to water scarcity reduced its capacity to carry out essential tasks, with fewer leaves per plant (Table 2), and the size of the leaf area (Table 3) may be causing low carbohydrates. These findings corroborated those of Dawood *et al.* (2014).

Table 4 results further showed that spraying with abscisic caused a significant decrease in the plant's concentration of carbohydrates. The spraying treatment with abscisic (0.2 mM) gave an average of 13.01 mg g^{-1}, with the control treatment with a higher average of 13.82 mg g^{-1}. As a growth regulator, abscisic (0.2 mM) closes the stomata to reduce water loss through transpiration, reducing CO_2 entry into the plant and lowering photosynthesis, decreasing glucose synthesis, which is necessary for carbohydrate production. These results were the same as those found by Ali *et al*., (2012)..

Findings in Table 4 demonstrated that potassium spraying significantly increased the overall concentration of carbohydrates. Specifically, an average of 16.31 mg g^{-1} resulted from the potassium spraying treatment (1000 mg L^{-1}) compared with 10.51 mg g^{-1} from the control treatment. Potassium's activation of numerous enzymes involved in the manufacture of carbohydrates may be due to this advantage, as evidenced by the plant's higher potassium concentration (Alhasany *et al*., 2019).

The results available in Table 4 further showed a significant interaction between the study factors, with the highest interaction in the control treatment of spraying with abscisic acid (0.2 mM) with the control treatment of potassium spray, under the effect of irrigation at 100% of the field capacity, garnering an average of 19.67 mg g^{-1}, while the lowest interaction was in the treatment of spraying with abscisic at 0.2 with the control treatment of potassium spraying under 25% of the field capacity, having an average of 9.64 mg g^{-1}. Given that potassium is necessary to synthesize enzymes, carbohydrate content

Table *5*. Effect of ABA and K on proline content in leaves under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	9.87	15.64	12.76
	1000	10.56	13.84	12.20
50	0	14.04	13.49	13.77
	1000	15.74	14.32	15.03
25	0	12.36	12.99	12.68
	1000	15.89	14.75	15.32
LSD$_{0.05}$		2.73		1.93
				TW Mean
TW *ABA	100	10.23	14.75	12.49
	50	14.89	13.91	14.10
	25	14.13	13.87	14.11
LSD$_{0.05}$		1.93		0.86
				K Mean
K*ABA	0	12.09	14.04	13.07
	1000	14.06	14.30	14.18
LSD$_{0.05}$		1.72		0.72
ABA		13.08	14.19	
LSD$_{0.05}$		0.72		

rises. Enzymes that combine low-molecular-weight molecules into high-molecular-weight ones are highly active. Thus, it helps transport carbs from formation to storage (Dawood *et al*., 2014).

Proline concentration (μg g^{-1})

More outcomes exhibited notable variations among the water stress treatments (Table 5). Irrigation at 50% and 25% of the field capacity resulted in significantly higher proline concentrations inside the plant, with averages of 14.11 and 14.10 μg g^{-1}, respectively; yet, treatment at 100% of the field capacity produced the lowest proline concentrations in the plant, at 12.49 μg g^{-1}. The plant's physiology protects its cells from water deficiency by preventing ROS compound damage and regulating its osmotic regulation, increasing its ability to withdraw water and nutrients and maintain cell elongation and opening. Stomata and carbon assimilation efficiency supported plant development under water scarcity because the proline is a compact and cohesive water shell that resists water stress (Ashraf and Foolad, 2007; Ouzounidou *et al*., 2014).

The results of Table 5 showed that spraying with abscisic meaningfully increased the concentration of proline, as the spraying treatment with abscisic (0.2 mM) gave an average of 14.19 μg g^{-1}; however, the control treatment produced an average of 13.08 μg g^{-1}. These findings supported El-Mahdy *et al*. (2021) findings that the plant's proline increase is a defensive response to abscisic acid, an inhibitory agent that stimulates proline accumulation in response to stress.

The findings demonstrated that potassium spraying significantly increased the plant's proline concentration: an average of 14.18 μg g^{-1} came from the potassium spraying treatment (1000 mg L^{-1}) compared with 13.07 μg g^{-1} from the control treatment. Potassium boosts proline, which controls cell osmotic pressure and reacts to stress. Preserving electrical equilibrium in cells, especially at ATP generation sites, controls photosynthesis (Dawood *et al*., 2014).

Results also demonstrated a significant interaction between the factors under investigation (Table 5). Specifically, the control treatment, which involved spraying abscisic acid at an average of 15.74 μg g^{-1} combined with potassium treatment at 1000 mg L^{-1} and irrigation at 50% of the field capacity, had the lowest interaction. Irrigation at 100% field capacity was part of the potassium spraying control treatment, with the average abscisic

Table *6*. Effect of ABA and K on SOD activity units under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	148.54	177.84	163.19
	1000	192.89	201.92	197.65
50	0	111.78	209.43	160.61
	1000	225.69	232.49	169.31
25	0	99.52	112.92	106.22
	1000	191.89	215.67	203.78
LSD$_{0.05}$		10.62		7.83
				TW Mean
TW *ABA	100	145.71	164.30	155.01
	50	168.74	220.96	194.85
	25	173.72	189.88	181.80
LSD$_{0.05}$		7.83		6.21
				K Mean
K*ABA	0	119.95	166.75	143.35
	1000	203.49	216.69	210.09
LSD$_{0.05}$				5.30
ABA		161.72	191.71	
LSD$_{0.05}$		5.35		

acid spraying rate at 9.87 µg g^{-1}. Drought causes the plant to create more proline because potassium increases the development of enzymes (Moussa and Abdel-Aziz, 2008; Moosavi, 2012; Ahmad *et al*., 2020).

Superoxide dismutase (SOD) activity (mg min^{-1})

The results enunciated notable differences between the water stress treatments (Table 6). Irrigation at 50% of the field capacity resulted in an average of 194.85 units mg^{-1} min^{-1} in SOD enzyme activity, with irrigation at 100% of the field capacity producing an average of 155.01 mg min^{-1} and irrigation at 25% of the field capacity, an average of 181.80 mg min^{-1}. In the first line of defense against oxidative stress, which generates free radicals (ROS), the SOD enzyme, one of the antioxidant enzymes, is crucial in eliminating the adverse effects of oxygen hydroxide and converting it to water and oxygen, much like what Abid *et al.* (2021) discovered.

Table 6 findings showed that spraying with abscisic caused a significant increase in the activity of the SOD enzyme, as the spraying treatment with abscisic (0.2 mM) gave an average of 191.71, and the control treatment gave an average of 161.72 mg min^{-1}. The increase in the effectiveness of the catalase enzyme can refer to the effect of abscisic acid in stimulating the antioxidant enzymes responsible for resisting water stress, including the catalase enzyme, which gets activated without the need for its intervention or may need its presence in some way to regulate activity. These results agreed with those of Abid *et al*. (2020).

The results in Table 6 also signified that spraying with potassium markedly increased the activity of the SOD enzyme, as the spraying treatment with potassium at 1000 mg l^{-1} gave an average of 210.09 mg^{-1} min^{-1}, with the control treatment only an average of 143.35 mg^{-1} min^{-1}. Potassium reduces converting active oxygen (ROS) by regulating stomata opening and closing and maintaining CO_2 fixation efficiency, preserving carbon assimilation efficacy, and cell organelle safety under water deficiency (Jasim *et al*., 2018).

A considerable interaction occurred between the study factors (Table 6), as the highest interaction was in the abscisic acid treatment spray (0.2 mM) with the treatment of potassium spray at 1000 mg l^{-1}, under the effect of 50% irrigation of the field capacity with an average of 232.49 mg^{-1} min^{-1}. Meanwhile, the lowest interaction was in the control spraying treatment with abscisic acid plus the control treatment for potassium spraying under the effect of 25% irrigation of the field capacity, showing an average of 99.52 mg^{-1} min^{-1}. Higher enzyme activity SOD results

Table *7*. Effect of ABA and K on catalase activity units under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	130.65	128.69	259.34
	1000	140.74	149.65	145.20
50	0	125.65	150.47	138.06
	1000	170.48	185.76	178.12
25	0	120.69	138.76	129.73
	1000	143.41	151.48	147.45
$LSD_{0.05}$		10.54		8.42
				TW Mean
TW *ABA	100	135.70	139.17	137.44
	50	148.07	168.12	158.09
	25	132.05	145.12	138.59
$LSD_{0.05}$		8.42		5.27
				K Mean
K*ABA	0	125.66	139.31	132.48
	1000	151.54	162.30	156.92
$LSD_{0.05}$		6.71		4.05
ABA		138.60	150.80	
$LSD_{0.05}$		4.05		

from abscisic acid activating antioxidant enzymes. Antioxidant enzymes like catalase benefit from potassium's reduction of free oxygen radicals (Sinha *et al*., 2013).

Catalase activity (mg^{-1} min^{-1})

The results in Table 7 indicate significant differences between the water stress treatments, as irrigation at 50% of the field capacity substantially increased catalase activity, with an average of 158.09 units mg^{-1} min^{-1}, and irrigation at 100% of the field capacity giving an average of 137.44 units mg^{-1} min^{-1}, which did not differ significantly with the 25% irrigation of the field capacity at an average of 138.59 units mg^{-1} min^{-1}. The catalase enzyme breaks down H_2O_2, a harmful consequence of metabolic activities when the plant receives stress. Thus, one of the most essential antioxidants, catalase, breaks down hydrogen peroxide (H_2O_2) into water and oxygen. These findings support Kabbadj *et al*. (2017) minimizing stress-induced damage.

The Table 7 results also showed that spraying with abscisic markedly increased catalase activity. The spraying treatment with abscisic at 0.2 mM gave an average of 150.80 units mg^{-1} min^{-1}, with the control treatment only an average of 138.60 units mg^{-1} min^{-1}. Abscisic acid activates stress-resistant enzymes, including catalase, which can be active without intervention but may need it to regulate its activity (Radhakrishnan and Lee, 2013).

Spraying with potassium noticeably increased catalase activity, as the potassium treatment spray at 1000 mg l^{-1} gave an average of 156.92 units mg^{-1} min^{-1}, and the control treatment produced only an average of 138.60 units mg^{-1} min^{-1} (Table 7). Amino acids and proteins dispersed in the cell cytoplasm may boost catalase's construction and efficiency. Increasing these enzymes helps water-stressed plant cells fight ROS, which acts on water-deficient-stressed cells (Fayed *et al*., 2021; Abed *et al*., 2022; Jaafar *et al*., 2022).

As shown in Table 7, a significant interaction between the experimental factors appeared, as the highest interaction was in the abscisic acid (0.2 mM) treatment spray with the spraying treatment with potassium (1000 mg l^{-1}) under the effect of 50% irrigation of the field capacity with an average of 185.76 units mg^{-1} min^{-1}. The lowest interference was in the control treatment of spraying with abscisic acid, plus the control treatment of potassium spray under the effect of 25% irrigation of the field capacity. Abscisic acid has an influential role in enzymes' activity, especially when the plant experiences environmental stress, and potassium also has an effectual role in the synthesis and regulation of enzymes within the plant (Rady *et al.,* 2021).

Table *8*. Effect of ABA and K on MDA under water stress.

TW (%)	K (mg l^{-1})	ABA (mM)		TW*K
		0	0.2	
100	0	23.76	25.89	24.83
	1000	20.78	19.72	20.25
50	0	44.67	30.78	32.24
	1000	29.79	21.91	25.85
25	0	48.65	34.69	41.67
	1000	32.56	28.79	30.68
$LSD_{0.05}$		8.03		6.92
				TW Mean
TW *ABA	100	22.27	22.81	22.54
	50	37.23	26.35	31.79
	25	40.61	31.74	36.18
$LSD_{0.05}$		6.92		4.28
				K Mean
K*ABA	0	39.06	30.45	34.76
	1000	27.71	23.47	25.59
$LSD_{0.05}$		5.04		3.02
ABA		33.37	26.96	
$LSD_{0.05}$		3.07		

Malondialdehyde (nmol g^{-1} FW)

The following results are available in Table 8. Significant differences emerged between the water stress treatments, as irrigation of 50% and 25% of the field capacity notably increased malondialdehyde (MDA), with averages of 31.79 and 36.18 nmol g^{-1} FW, respectively, and the irrigation treatment at 100% of the field capacity averaged 22.54 nmol g^{-1} FW protein. The reason for the increase in MDA concentration may be due to the hydrogen peroxide, which reacts with superoxide to form hydroxyl radicals, one of the active oxygen species (ROS), causing oxidation of cell membranes and increasing the content of malondialdehyde (Ouzounidou *et al.,* 2014).

The spraying with abscisic caused a significant decrease in MDA, as the treatment spray with abscisic (0.2 mM) gave an average of 26.96 nmol g^{-1} FW protein, while the control treatment gave an average of 33.37 nmol g^{-1} FW. This drop might be because of abscisic acid (ABA), which greatly lowers the buildup of MDA in plant leaves because of acid buildup and abscisic acid due to water stress, which hurts the production of malondialdehyde (Rady *et al*., 2021).

The results also showed that spraying potassium greatly reduced MDA. The treatment with 1000 mg L^{-1} potassium spray gave an average of 25.59 nmol g^{-1} FW, while the control treatment gave an average of 34.76 nmol g^{-1} FW. The decrease in malondialdehyde may refer to the fact that spraying potassium increases the relative water content by improving the plant’s efficiency in absorbing water and nutrients, reducing damage to cell membranes in plants exposed to drought, in addition to its lowering non-enzymatic antioxidants produced for defensive purposes. Therefore, the study can say that potassium is vital in lessening the harmful effects of drought stress. This result agreed with Abdel Latef *et al.* (2021).

Table 8 results indicated further significant interaction between the experimental factors, as the highest interaction was in the control treatment with abscisic spraying with the control treatment of spraying potassium under the effect of 25% irrigation of the field capacity giving an average of 48.65 nmol g^{-1} FW, while the lowest interaction was in the treatment of spraying with abscisic (0.2) with potassium spraying treatment at 1000 mg l^{-1} under irrigation of 100% of field capacity producing an average of 19.72 nmol g^{-1} FW. The increase can be attributable to malondialdehyde and the role of some active oxygen species that contribute directly or indirectly to MDA.

CONCLUSIONS

ABA and potassium alone and, in combination, increased proline, TSC, SOD, and CAT activities, increasing plant height, leaf number, and leaf area. However, ABA and potassium-treated plants had higher TSC, indicating that the combined treatment reduced the suppressive effect of water shortage by improving plant growth and antioxidant systems.

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