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EFFECT OF GLYCINE BETAINE, SALICYLIC ACID, AND POTASSIUM ON DIFFERENT TRAITS OF SOYBEAN CROP UNDER WATER STRESS

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ABSTRACT

This study was aimed to investigate the role of glycine betaine, salicylic acid, and potassium in supporting soybean plants grown under water stress. A field experiment was conducted at Wasit Governorate during the autumn seasons of 2022 and 2023. randomized complete block design (RCBD) with split plot using arrangement and three replications, conditions treatments of water depletion levels of 30%, 45%, and 60%. Water treatments were allocated to the main plots, While the treatments, which included A_0 (control treatment) of dry seeds and distilled water spray, A_1 (50 mmol L^{-1} Glycine betaine seed soaking), A_2 (300 mg L^{-1} salicylic acid spray), A_3 (50 m mol L^{-1} Glycine betaine seed soaking and 300 mg L^{-1} salicylic acid spray), A_4 (7.2 g L^{-1} potassium spray), A_5 (50 mmol L^{-1} Glycine betaine seed soaking and 7.2 g L^{-1} potassium spray), and A_6 (combination of the above treatments), were assigned to the subplots. The results indicated non significant differences among irrigation treatments at 30% and 45% water depletion in plant height, leaf area, chlorophyll content in the second season, plant dry weight, membrane stability, potassium content and seed yield in both seasons. However, plants subjected to irrigation at 60% water depletion showed higher average proline content (2.7 and 2.8) µmol g^{-1}.The interaction between plant support treatments and irrigation was statistically significant in plant height, leaf area, chlorophyll content, and plant dry weight.

Keywords: anti-transpiration ,drought stress, water amount, , seeds yield
***Part of Ph.D. dissertation of 1st author**

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INTRODUCTION

Soybean (*Glycien max* L) is considered a significant leguminous crop globally due to its high oil and protein content in seeds, essential for human and animal nutrition. However, its cultivation still faces various challenges in the environmental conditions of Iraq, including the crop's sensitivity to moisture. Several studies have indicated that water stress leads to a reduction in growth characteristics and some physiological traits of soybean, such as leaf area, plant height, chlorophyll content, relative water content, proline content, and dry weight. As a result, there is a decrease in net photosynthetic rate and accumulated dry matter (Adi &June,2018). Iraq is classified as a region with arid and semi-arid climates, due to the lack of rainfall and diminishing water resources, and thus low food productivity. Since water stress is one of the most important obstacles to plant growth, development and production, and with the increasing population, it has become necessary to achieve acceptable production per unit area through appropriate irrigation scheduling and good efficiency in water consumption for basic crops in the agricultural production process, with the aim of achieving food security under

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conditions Water Scarcity. Drought stress in the natural plant environments lead to an increase in the concentration of ions in the protoplasm to toxic levels. This leads to protein degradation, membrane fusion accumulation of organic acids, etc which causes physiological changes that negatively reflect on growth, such as a decrease in leaf area and accumulation of dry matter (Serdar et al,2011). the water stress problems, It was necessary to follow some agricultural practices that aim to overcome the physiological symptoms that appear on plants growing in dry environments. Technique of seeds priming can be used to improve the viability and seeds vigour under drought stress or spraying plants with anti-transpiration and foliar fertilization are important practices in dry and semi-arid areas to reduce the harmful effects of water stress (Saudi, 2017). Glycine betaine is an amino acid that has important physiological roles,for plant growth and development such as osmotic regulation, which maintains water balance under water stress conditions (Shekari,2015, Zein,2002). Salicylic acid is one of the antitranspirants and has many physiological roles such as controlling the opening and closing of stomata, encouraging flowering, delaying aging, stimulating production, and is considered one of the antioxidants that work to displace free radicals. The effectiveness of salicylic acid is associated with the defense system in the direction of eliminating these toxins, which makes plants more adaptive under water stress conditions (Ahmed &Salih,2023, Al-Khafaji &Al-Jubouri,2023;Kareem &Michael, 2017). The results of Odeh (Odeh,2015) showed that spraying soybean plants with three concentrations of salicylic acid (0, 300, 400, and 500) mg L^{-1} resulted in the superiority of the concentration of 300 mg L^{-1} with the highest average for leaf area, plant height, and chlorophyll content index compared to the other concentrations, which produed the control treatment the lowest average for the above traits. Potassium is one of the main elements that plants need, due to its important role in many vital physiological processes, such as controlling the mechanism of opening and closing of stomata, as well as stimulating many enzymatic reactions in plants (Ati *et al*,2016 , Al-Khafaji & Jubouri,2023). Many studies have indicated the role of potassium in reducing the negative effects of water stress and improving the growth and productivity of plants growing in dry environments.

MATERIALS AND METHODS

A field experiment was conducted to cultivate soybean crop during the fall autumn seasons of 2022 and 2023 at the Izza Agricultural Farm at Wasit Governorate. A randomized complete block design withm split-plot arrangement in three replications were used. The main plots included three irrigation treatments at 30, 45, and 60% depletion of available water, which were coded as (E_1, E_2, and E_3). The subplots included seven treatments:

1. Control treatment (dry seeds and water spray only), coded as A_0
2. Seed soaking with glycine betaine at a concentration of 50 mM L^{-1}, coded as A_1
3. Seed soaking with glycine betaine at a concentration of 50 mM L^{-1} and spraying plants with potassium at a concentration of 7.2 g L^{-1}, coded as A_2
4. Seed soaking with glycine betaine at a concentration of 50 mM L^{-1} and spraying plants with salicylic acid at a concentration of 300 mg L^{-1}, coded as A_3
5. Spraying plants with salicylic acid at a concentration of 300 mg L^{-1}, coded as A_4
6. Spraying plants with potassium at a concentration of 7.2 g L^{-1}, coded as A_5
7. Seed soaking with glycine betaine at a concentration of 50 mM L^{-1} and spraying plants with salicylic acid at a concentration of 300 mg L^{-1} and potassium at a concentration of 7.2 g L^{-1},The experimental field was plowed and divided into plots of 2 × 3 m each. Each experimental unit consisted of five rows with a distance of 60 cm between each row and 20 cm between plants, 2 m were left between replicates and main treatments to prevent water movement. Planting was carried out on5/6/2022and2023. Superphosphate fertilizer (46 % P_2O_5) was used at a rate of 200 kg ha^{-1} in a single application during land preparation. Urea fertilizer (46% N) was added at a rate of 160 kg ha-1 in two applications at planting and flowering .and main treatments to prevent water movement. Planting was carried out

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Soil moisture measurement

The field capacity of the soil was determined by estimating the relationship between the structural stress of a sieved soil sample and the volumetric moisture content at stresses (33, 100, 200, 500, 1000, and 1500 kPa). This was used to determine the available water in the soil from the difference between the moisture content at the field capacity of the soil and the wilting point. The volumetric method was used to measure the soil moisture by taking samples using an auger at a depth of 20 and 40 cm before irrigation and two days after irrigation. They were placed in aluminum cans and weighed while wet, then placed in a microwave for 13 minutes and weighed after drying.The volumetric moisture content was estimated based on the bulk density of the soil according to the following equation .

$\theta = Pw \times \beta\partial$

θ = Volumetric moisture content

pw = Moisture content on a weight basis

$\beta\partial$ = Bulk density, µg $m^{-}3$

Irrigation was scheduled based on moisture measurement and the equation was used:

$d = (\theta fc - \theta d) \times D$

d = Depth of water added

θfc = Moisture content at field capacity

θd = Moisture content before irrigation

D = Depth of the root zone

Soybean plants were sprayed with salicylate and potassium in the early morning. A backpack sprayer was used for this purpose and a surfactant such as zahi was used as a spreading agent to break the surface tension. The control treatment was sprayed with water only.

Studied: Measurements were taken at the beginning of pod formation for five plants.

Plant height (cm) , Leaf area (dm^2) ,Chlorophyll content (mg 100 g^{-1} f.w.), Leaf proline content (µmol g^{-1} f.w.) , Potassium content in leaves (%) , Dry weight of the plant (g plant), Seed yield (tons ha^{-1})

Relative water content of leaves (%): (The third leaf from the top of the plant) was taken and discs with a diameter of 2 cm were taken from it. The relative water content was estimated using the following equation: (Yang et al,2003)

$$R.W.C = \frac{FW - DW}{TW - DW} x\,100$$

where:

FW = fresh weight (g)

TW = filled weight (g)

DW=dry weight (g)

Membrane stability (%): Membrane stability was estimated according to the paremachandra method and according to the following equation: (Premachandra &Shimada,1988)

$$\text{Cell membrane stability (\%)} = \frac{L}{M}\, X\,100$$

Where:

L = living tissue filtrate

M = dead tissue filtrate

RESUITS AND DISCUSSION

Plant height (cm): A result of Table (1) shows a significant effect of the study factors and their interaction on plant height. The plants of treatment E_3 recorded the lowest average plant height of 80.1 and 81.3 cm, respectively, for the two seasons. They differed significantly from the two depletion treatments, E_1 and E_2, (88.9 and 89.6 cm and 85.2 and 87.6 cm, respectively), for the two seasons with a non-significant difference between them for the second season. This is attributed to a decrease in the relative water content (Table 5), which leads to a disruption in the physiological processes of plant cells, reducing their ability to divide and elongate, in addition to reducing the activity of growth-promoting hormones due to their negative impact on the reduction of leaf area, which reflects on the work of auxins and thus the elongation of the internodes. It could be also be attributed to the occurrence of disturbances in the enzyme system due to the lack of water in the chloroplasts, thus inhibiting the process of building and stopping the division and development of growth. Treatment A_1 recorded the highest average plant height of 89.4 and 89.1 cm, respectively, for two seasons compared to the control treatment, which recorded the lowest average at 80.5 and

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83.1 cm, for the two seasons respectively. This could be due to the role of salicylic acid in the development of plant growth through the rapid emergence of seedlings and the establishment of strong plants with an effective and deep root system in the soil, which helped the plant to absorb water from different depths at a good growth rate. Potassium also helped to increase cell division and elongation of the internodes due to its vital role in activating enzymes for the synthesis of proteins and growth regulators(Al-Jubouri & Shaker,2019 , Hassan,Ibraheem,2020)The interaction between the two factors was significant, as the combination of E_1A_1 for the first season and the combination of E_2A_1 for the second season recorded the highest averages of 98.0 and 94.7 cm, respectively, compared to the combination of E_3A_0, which recorded the lowest average for plant height of 75.7 and 80.0 cm, for the two seasons respectively.

Table 1. Effect of the study factors and their interaction on the mean plant height (cm) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
2022	A0	85.0	80.7	75.7	80.5
	A1	98.0	87.4	82.9	89.4
	A2	89.2	85.7	81.4	85.4
	A3	87.3	82.7	81.2	83.6
	A4	86.8	87.7	77.3	83.9
	A5	86.3	84.4	81.7	84.1
	A6	90.0	88.1	80.2	86.1
	LSD		6.6		1.2
	Mean	88.9	85.2	80.1	
	LSD		2.7		
autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
3202	A0	86.0	83.3	80.0	83.1
	A1	90.7	94.7	82.0	89.1
	A2	89.0	88.0	80.3	85.8
	A3	93.0	87.0	79.5	86.5
	A4	89.3	90.0	80.0	86.4
	A5	88.3	85.0	83.3	85.5
	A6	91.0	85.0	84.0	86.7
	LSD		3.5		1.9
	Mean	89.6	87.6	81.3	
	LSD		2.7		

Leaf area (dm^2): Result of Table (2) shows a significant effect of the study factors and their interaction on leaf area. The plants of the E_3 depletion treatment recorded the lowest average at 31.7 and 34.5 dm^2, for the two seasons respectively. They differed from the E_1 depletion treatment with 34.4 and 36.8 dm^2, for the two seasons respectively. The reduction in leaf area is attributed to the decrease in the relative water content (Table 5), which led to a decrease in the water potential of the leaves, leading to a decrease in cell size and its ability to elongate and expand. Also, water stress conditions directly affect leaf area, where the increase in size stops before division and division stops before photosynthetic inhibition. Since the development of leaf area is an indicator of the function of the photosynthetic process, or it could be due to the fact that water deficiency due to the decline in turgor pressure, which in turn indicates the rate of elongation of plant cells that need after division to a force that pushes their walls to expand (Abdul Qados, 2014, Al-Awda &Khaiti,2008). Also, the lack of soil moisture makes the plant tend to reduce its leaf area as a state of adaptation. Treatment A_2 recorded the highest value for the trait, which was 34.2 dm^2 for the first season, and treatment A_1 recorded the highest average of 37.0 dm^2 for the second season, compared to the control A_0 (31.3 and 32.5dm^2, for the two seasons respectively). The reason is attributed to the effect of stimulating the seeds with glycine betaine and spraying with potassium and salicylate. Since the seeds that emerged early were faster in

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forming a root system capable of absorbing water and nutrients, this was reflected in the number of leaves and leaf area of the plant. Potassium and salicylate also have a positive role in reducing the negative effects of water stress conditions by controlling the opening and closing of stomata, which reduces the loss of water necessary for elongation and division. The interaction achieved significant differences as shown in Table (2). The E_1A_2 combination recorded 35.5 dm^2 for the first season, which differed significantly from the E_3A_0 (29.0 dm^2). While the E_1A_3 combination recorded 39.0 dm2 for the second season, which differed significantly from the E_1A_0 combination, which recorded a value of 35.3 dm^2. While the combination of E_3A_0 recorded lowest average of 30.3 dm^2.

Table 2. Effect of the study factors and their interaction on the mean leaf area (dm^2) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
2022	A0	33.7	31.3	29.0	31.3
	A1	34.2	33.0	32.2	33.1
	A2	35.5	33.6	33.5	34.2
	A3	34.0	32.3	30.7	32.3
	A4	34.0	33.3	31.4	32.9
	A5	34.7	34.3	32.2	33.7
	A6	34.6	32.9	33.2	33.5
	LSD		1.14		0.56
	Mean	34.4	33.0	31.7	
	LSD		0.62		
autumn seasons	**Treatments**	**Depletion of available water % 30 % E1**	**45 % E2**	**60% E3**	**Mean**
3202	A0	35.3	32.0	30.3	32.5
	A1	37.0	36.7	37.3	37.0
	A2	36.0	36.0	33.7	35.2
	A3	39.0	35.0	35.0	36.3
	A4	37.3	35.0	35.0	35.7
	A5	36.3	35.7	35.7	35.9
	A6	36.7	36.0	34.3	35.6
	LSD		2.56		1.98
	Mean	36.8	35.2	34.5	
	LSD		1.17		

Chlorophyll content (mg g^{-1})

Result of Table (3) shows a significant effect of the study factors and their interaction on the chlorophyll content in the leaves. The plants of treatment E_3 recorded the lowest average of 19.4 and 20.7 mg g^{-1}, for the two seasons respectively; they differed significantly from treatment E_1, which did not differ significantly from treatment E_2 in the second season, which recorded 22.3 and 21.7 mg g^{-1}. This could be due to the fact that the decrease in water availability led to a deficiency in the nutrients that are involved in the synthesis of chlorophyll. In addition to the decline in the process of carbon fixation due to the closure of stomata and the disruption of the diffusion of CO2, leading to a decrease in plant pigments, including chlorophyll. (Al-Jubouri & Shaker,2019, Cerezinia *et al*, 2016). Treatment A_1 recorded the highest average of 22.2 mg g^{-1} for the first season, which did not differ significantly from treatments A_6, A_5, and A_3. However, in the second season, treatment A_1 recorded the highest average of 23.9 mg g^{-1}, compared to the control A_0, which recorded the lowest average of 19.3 mg g^{-1}. In addition, stimulating the seeds with Glycine butaine produced plants that were able to absorb water and nutrients efficiently , The increase in chlorophyll in the leaves of soybean plants when the seeds are soaked in Glycine coyld be due to the increase in the choline compound in the leaves, which inhibits the activity of the enzyme Chlorophyllase and prevents the conversion of chlorophyll (Shihab &Hamza,2020).The results also showed a significant interaction between the two factors. The combination E_1A_1 recorded the highest (23.9 and 26.3) mg g-1, for the two seasons respectively, compared to the combination

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E_1A_0, which recorded the lowest values of 20.5 and 19.0 mg g^{-1}, respectively. At the E_3 depletion level, the combinations E_3A_3 and E_3A_1 outperformed both seasons (23.4 and 23.3, respectively), compared to the combination E_3A_0, which recorded 18.0 mg g^{-1} for both seasons.

Table 3. Effect of the study factors and their interaction on chlorophyll content (mg g^{-1})for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
2022	A0	20.5	19.5	18.0	19.3
	A1	23.9	6.22	2.02	22.2
	A2	22.6	2.20	6.19	20.8
	A3	20.6	4.32	1.02	21.4
	A4	22.9	20.9	19.5	21.1
	A5	23.1	.721	.719	21.5
	A6	22.6	23.2	18.6	21.5
	LSD		1.20		0.76
	Mean	22.3	6.12	4.19	
	LSD		0.67		
autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
3202	A0	19.0	20.8	18.0	19.3
	A1	26.3	22.2	23.3	23.9
	A2	19.0	22.4	22.0	21.1
	A3	22.7	21.8	21.0	21.8
	A4	19.7	23.8	19.0	20.8
	A5	25.7	22.4	20.3	22.8
	A6	19.8	20.9	21.0	20.6
	LSD		2.00		1.10
	Mean	21.7	22.0	20.7	
	LSD		0.90		

Proline content (µmol g^{-1})

Result of Table (4) shows a significant effect of the study factors on the proline content of the plant. The plants of treatment E3 recorded the highest average of 2.7 and 2.8 µmol g^{-1}, for the two seasons respectively, Treatment E^1 recorded the lowest average of 2.0 and 2.4 µmol g^{-1}, for the two seasons respectively,. This could be due to the fact that water deficiency stimulates the enzymatic activity of protein-degrading enzymes by the enzyme Proteinase, as well as causes a decrease in the pH value of the cell sap of the leaf tissue, which causes an increase in the accumulation of proline, which is one of the amino acids that has the ability to increase the osmotic potential in plants exposed to drought (Mafakheri *et al*,2010. In addition, the decrease in protein synthesis in the cell increased the concentration of proline to resist damage caused by drought through osmotic adjustment, which is considered an adaptive state by the plant exposed to water stress (Hassan,2020). Treatment A_3 and A_4 and A_5 recorded the highest average (2.6, 2.6, and 2.7 µmol g^{-1}) respectively, with a non-significant difference between them, for first season. Also, treatments A_3 and A_5 recorded the highest average in the second season (3.3 and 3.0 µmol g-1, respectively), with a non-significant difference between them, as well as compared to treatment A_0, which recorded a value of 1.9 and 2.2 µmol g-1 for the two seasons, respectively. This indicates that the treatment of stimulating the seeds with Glycine butaine and spraying the plants with salicylic and potassium increased the level of proline in the leaves, which is one of the defense mechanisms to reduce the damage of water stress.

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Table 4. Effect of the study factors and their interaction on proline content (μmol g^{-1}) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
2022	A0	1.2	2.0	2.6	1.9
	A1	1.7	2.6	2.6	2.3
	A2	1.6	2.6	2.9	2.4
	A3	2.8	2.0	3.0	2.6
	A4	2.5	2.3	2.9	2.6
	A5	2.4	3.0	2.8	2.7
	A6	2.0	2.8	2.3	2.4
	LSD		N.S		
	Mean	2.0	2.5	2.7	0.43
	LSD		0.31		
autumn seasons	**Treatments**	**Depletion of available water %**			**Mean**
		30 % E1	**45 % E2**	**60% E3**	
3202	A0	1.9	2.2	2.5	2.2
	A1	2.6	2.7	2.7	2.6
	A2	2.2	2.7	2.4	2.4
	A3	3.2	3.2	3.5	3.3
	A4	1.8	2.8	2.7	2.4
	A5	2.8	2.7	3.6	3.0
	A6	2.5	2.8	2.0	2.4
	LSD		N.S		0.57
	Mean	2.4	2.7	2.8	
	LSD		0.20		

Relative water content of leaves (%)

Result of Table (5) shows significant effect of the study factors and their interaction on the relative water content of the plant. The plants of treatment E_1 outperformed with the highest average of 86.6% and 87.4%, for the two seasons respectively, which differed significantly from treatments E_2 and E_3. This could be due to the fact that water deficiency weakens the plant's ability to absorb water, which leads to a decrease in the relative water content in plant tissues. The decrease in leaf water due to the lack of flow from the xylem tissue and the pressures of evaporation and transpiration due to high temperatures, the plant becomes devoid of water balance (Yang et al,2003, Hassan,2020).The result shows that treatment A_5 produed the highest value for relative water content, at 88.8% for the first season, while treatment A_1 outperformed with an average of 86.0% for the second season, which did not differ significantly from treatments A_3 and A_5, compared to the control treatment A_0, which recorded 80.1% and 82.8%, for the two seasons respectively. This could be due to the fact that stimulating the seeds with Glycine butaine led to osmotic regulation in the cells, as it is one of the active and compatible solutions that accumulate and help plants to improve water relations. In addition, potassium plays an important role in the leaf, especially with regard to the guard cells located around the stomata, because of its responsibility for the swelling of those cells and reducing water loss through transpiration, especially when water stress occurs, which increases the crop's ability to tolerate drought. Potassium represents the highest concentration of dissolved positive ions in the plant cell sap, it maintains ion balance and regulates water balance in the plant tissue and maintains cell swelling (Shihab &Hamza,2020). In addition, salicylic acid has a positive role in reducing the negative effects of water stress conditions by controlling the opening and closing of stomata, which reduces water loss and preserves plant water. The result shows a significant interaction between the study factors, as the combination E_1A_5 outperformed with the highest value of 93.0%, compared to the combination E_1A_0, which produed an average of 81.0% for the first season. However, the combination E_3A_0 produed the lowest average for the trait in both seasons. The combination E_1A_1 also outperformed for the second season, with an average of 90.0%, compared to the combination E_1A_0 with the lowest average of 85.0%.

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Table 5. Effect of the study factors and their interaction on relative water content of leaves (%) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
2022	A0	81.0	79.9	79.5	80.1
	A1	89.3	82.5	80.6	84.1
	A2	84.5	80.4	79.9	81.6
	A3	91.4	86.2	78.4	85.3
	A4	83.1	80.5	80.1	81.2
	A5	93.0	91.7	81.8	88.8
	A6	84.2	82.1	78.7	81.7
	LSD		1.97		1.3
	Mean	86.6	83.5	79.9	
	LSD		0.95		
autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
3202	A0	85.0	83.7	79.7	82.8
	A1	90.0	84.7	83.3	86.0
	A2	88.0	83.7	80.7	84.1
	A3	86.0	86.3	84.0	85.4
	A4	87.3	84.0	80.3	83.9
	A5	88.0	85.7	83.3	85.6
	A6	87.3	85.0	81.7	84.6
	LSD		2.7		1.71
	Mean	87.4	84.7	81.9	
	LSD		1.80		

Vegetative dry weight (g plant^{-1})

The results indicate a significant effect of the study factors and their interaction on vegetative dry weight (Table 6). The plants of treatment E_1 recorded the highest average of 89.2 and 89.1 g plant^{-1} for the two seasons, respectively, which did not differ significantly from treatment E_2 (87.2 g and 87.5 g, for the two seasons respectively), while it differed significantly from treatment E_3, which recorded the lowest weight (80.4 g and 82.5 g) for the two seasons respectively. This could be due to the decrease in the components of dry matter such as plant height and leaf area, which negatively affected the dry weight of the plant (Table 1 and 2). Water stress affected the size of the source, which led to a decrease in the rate of photosynthesis and thus a decrease in the dry weight of the plant, on the production and accumulation of dry matter and its relationship to root growth (Al-Fahdawi,2015). Treatment A_3 in the first season produed the highest value for the dry weight of the plant, which was 90.1, which did not differ significantly from A_1, A_2, and A_5. Treatment A_1 recorded 89.2 g plant^{-1} in the second season, which did not differ significantly from A_2, A_3, A_4, and A_5, compared to the control A_0, which recorded the lowest value of 81.3 and 81.8 g plant^{-1} for both seasons. The lack of dry weight in treatment A_0 is due to the lack of plant height, leaf area, and chlorophyll content (Table 1, 2, and 3), which led to the lack of accumulation of dry matter in treatment A_0. The results also show that the combination of factors that enhance drought tolerance improved growth indicators more than their presence individually. This could be due to the fact that the stimulation with Glycine butaine, spraying with salicylic acid, and potassium play an important role in the formation of a root system with the efficiency of absorbing water and nutrients under the condition of moisture deficiency, and thus maintaining the physiological processes and their reflection on the accumulation of dry matter. Salicylic acid also has regulatory roles for the processes of construction and demolition in the plant (El-Bahay &changes,2002). The results also showed a significant interaction between the two factors as.the combination E_2A_5 outperformed for the first season with the highest weight of 99.0 g plant^{-1}.In the second season, the combination E_1A_1 recorded the highest value of 95.7 g, while the combination E_3A_0 recorded the lowest values of 76.7 and 77.3 g plant^{-1} for the two seasons, respectively.

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This is due to the reduction of plant height, leaf area, chlorophyll content, and relative water content of this combinatio (Table 1, 2, 3, 5).

Table 6. Effect of the study factors and their interaction on vegetative dry weight (g plant^{-1}) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
2022	A0	86.3	81.0	76.7	81.3
	A1	87.3	87.3	84.0	86.2
	A2	92.0	90.3	76.0	86.1
	A3	97.0	89.7	83.7	90.1
	A4	83.0	87.0	81.7	83.9
	A5	90.7	99.0	79.3	89.6
	A6	88.3	76.3	81.7	82.1
	LSD		7.39		4.97
	Mean	89.2	87.2	80.4	
	LSD		3.84		
autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
3202	A0	85.0	83.0	77.3	81.8
	A1	95.7	89.3	82.7	89.2
	A2	92.3	88.0	84.3	88.2
	A3	93.3	86.0	80.0	86.4
	A4	81.0	87.7	87.3	85.3
	A5	92.0	88.3	85.0	88.4
	A6	84.3	90.0	77.7	84.0
	LSD		8.00		5.11
	Mean	89.1	87.5	582.	
	LSD		4.00		

Membrane stability (%)

The results indicate a significant effect of the study factors and the absence of interaction on membrane stability (Table 7). The results indicated superiority of E_1 over E_3 with statistical significance in membrane stability (80.3 and 83.0%) compared to E_3 treatment (74.8 and 76.6% for the two seasons. This could be attributed to the fact that increasing water stress levels leads to damage to the plasma membrane due to the generation of free radicals (ROS), which oxidize it, leading to the loss of the plasma membrane of its basic function, which is quantitative and directional regulation of water, quantitative, qualitative and directional regulation of solutes (from the cell to it), which leads to the appearance of the effect of stress in the plant, and that maintaining the membranes in their stability and safety under water stress conditions is considered one of the most important elements of water stress tolerance (Hassan,2020). The results also show that treatment A_4 produed the highest value for membrane stability, at 82.6% for the first season, while treatment A_1 recorded the only (83.8%) for the second season, compared to treatment A_0, which recorded the lowest (74.4 and 71.1%) for the two seasons respectively, This could be attributed to the fact that foliar application of potassium fertilizer led to the maintenance of the osmotic pressure of the cells through the control of the opening and closing of stomata and the transfer and accumulation of chemical compounds, including proline, which is involved in the formation of proteins that have a role in damage tolerance and charge balance inside the plant under water stress conditions, in addition to an increase in nutrient absorption, including phosphorus, which contributes to nutritional balance through increasing the permeability of cell membranes. Also, the stimulation with Glycine led to the formation of a root system with efficiency in nutrient absorption, thus maintaining physiological processes

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Table 7. Effect of the study factors and their interaction on membrane stability (%) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
2022	A0	81.3	73.3	68.7	74.4
	A1	83.2	81.0	76.0	80.1
	A2	78.0	76.3	71.7	75.3
	A3	81.3	82.3	74.3	79.3
	A4	83.0	82.7	82.0	82.6
	A5	79.4	82.0	75.3	78.9
	A6	76.5	82.0	75.7	78.1
	LSD		N.S		5.48
	Mean	80.3	79.9	74.8	
	LSD		1.85		
autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
3202	A0	80.3	67.7	65.3	71.1
	A1	86.7	83.3	81.3	83.8
	A2	83.3	80.7	75.0	79.9
	A3	82.7	83.7	78.0	81.4
	A4	81.3	76.7	77.7	78.6
	A5	82.5	82.7	81.0	82.1
	A6	84.3	81.0	78.0	81.1
	LSD		N.S		4.63
	Mean	83.0	79.4	76.6	
	LSD		2.9		

Potassium content in leaves (%)

Results shown in Table (8) indicate a significant effect of water stress treatments on potassium content, as plants of treatment E_1 recorded the highest average of 2.6 and 2.9%, respectively, for the two seasons respectively, which did not differ significantly from treatment E_2, while treatment E3 recorded the lowest average of 2.1 and 2.2%, for the two seasons respectively. This could be attributed to the fact that the decrease in soil water potential causes a decrease in irrigation water quantities, which reduced the plant's absorption of potassium due to the deposition of lignin (lignification) and thickening of cell walls in the roots of plants exposed to high moisture depletion, which leads to the accumulation of ions in the root xylem and their non-uniform distribution within the plant(Khalaf &Mahidi,2020; Odeh,2015, Okab &Abed,2022). The results also show that there is a significant effect of foliar and seed soaking treatments, as treatment A_6 recorded the highest value for potassium content in leaves, reaching 2.9% for the first season, while treatment A_5 recorded the highest value of 2.9% for the second season, compared to the control treatment A_0, which recorded the lowest value of 1.8 and 2.0%, respectively, for the two seasons. This could be attributed to the fact that foliar application of potassium fertilizer and stimulation of seeds with Glycine betaine led to an increase in potassium content through the principle of compensation and the efficiency of plants in extracting nutrients, as the stimulation of seeds led to the formation of a root system with high efficiency(Ati *et al*,2016). In addition to the role of salicylic acid in regulating many physiological processes in the plant, including opening and closing of stomata, photosynthesis, and ion absorption, in addition to increasing the permeability of cell membranes that contribute to increasing the absorption of nutrients, including potassium.

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Table 8. Effect of the study factors and their interaction on Potassium content in leaves (%) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
2022	A0	2.0	1.9	1.5	1.8
	A1	2.9	2.5	2.4	2.6
	A2	2.6	2.3	2.2	2.3
	A3	2.1	2.4	1.9	2.2
	A4	2.5	2.2	1.7	2.1
	A5	2.6	2.5	2.3	2.4
	A6	3.4	2.9	2.5	2.9
	LSD		N.S		5.48
	Mean	62.	2.4	12.	
	LSD		0.29		
autumn seasons	Treatments	Depletion of available water % 30 % E1	45 % E2	60% E3	Mean
3202	A0	2.3	2.0	1.8	2.0
	A1	2.8	3.1	2.5	2.8
	A2	2.9	2.4	2.2	2.5
	A3	2.4	2.8	2.5	2.6
	A4	3.1	2.4	2.2	2.6
	A5	3.1	3.0	2.4	2.9
	A6	3.5	3.0	2.1	2.8
	LSD		N.S		0.46
	Mean	92.	2.7	22.	
	LSD		0.40		

Seeds yield (tons ha^{-1})

Result of Table (9) shows a significant effect of the study factors and their interaction on seed yield for the plants of treatment E_1 and E2 recorded the highest average seed yield of(1.7 and 1.7) tons ha-^{1} for the first season (1.8 and 1.8)tons ha^{-1} respectively for the two season, they differed Significantly from treatment the E3 which produed the lowest yield of(1.2 and 1.4) tons ha-1 for the two seasons, . The reduction for the decrease in seed yield for the E_3 irrigation treatment could be to the effect of the lack of water in the volume of the source resulting from the decrease in the rate of photosynthesis and the accumulation of dry matter, which was reflected in the components of the yield. The main seed weight, number of pods, and number of seeds per pod. The A_6 spraying treatment recorded weight (1.9 and 1.8) tons ha-1 for the two seasons, which did not differ significantly from A_5 and A_4 for The first season. The first, A_1, A_3, A_4, and A_5 for the second season, while treatment A_0 recorded the lowest weight (1.2 and 1.4) tons ha-1 for the two seasons, respectively. This could be due to the stimulation with glycine betaine and spraying with salicylic acid and potassium combined under water stress led to the continuation of the physiological processes and their impact on the accumulation of the substance. dry crops, which led to the distribution of plant metabolic products in favor of the yield components(Taiz &Zeiger,2010). The results also show that the combination of ingredients that withstand water stress improved the vegetative growth indicators (Tables 1, 2 and 3) more than their presence alone. The results also showed a significant interaction between the two factors, as the combination E_2A_6 was superior in giving The highest value was 2.0 tons ha-1 for the two seasons compared to the E_3A_0 combination, which gave the lowest value of 1.1 and 1.2 tons ha^{-1} for the two seasons, respectively.

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Table 8. Effect of the study factors and their interaction on Seed yield (tons ha^{-1}) for the two seasons (2022-2023)

autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
2022	A0	1.3	1.2	1.1	1.2
	A1	1.7	1.8	1.2	1.6
	A2	1.6	1.4	1.0	1.4
	A3	1.9	1.8	1.2	1.6
	A4	1.8	1.7	1.4	1.7
	A5	2.0	1.8	1.3	1.7
	A6	1.9	2.0	1.5	1.9
	LSD		0.5		0.3
	1.7	1.7	1.7	1.2	
	LSD		0.2		
autumn seasons	Treatments	Depletion of available water %			Mean
		30 % E1	45 % E2	60% E3	
3202	A0	1.6	1.5	1.2	1.4
	A1	1.7	1.8	1.4	1.6
	A2	1.5	1.9	1.1	1.5
	A3	2.0	2.0	1.5	1.8
	A4	2.0	1.8	1.5	1.8
	A5	1.8	1.9	1.4	1.7
	A6	2.0	2.0	1.4	1.8
	LSD		0.4		0.3
	Mean	1.8	1.8	1.4	
	LSD		0.2		

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

The authors declare that they have not received a fund.

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تاثير الكلايسين بيتان وحامض السالسلك والبوتاسيوم في بعض الصفات لمحصول فول الصويا تحت الشد المائي.

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المستخلص

لدراسة دور الكلايسين بيتان وحامض السالسلك والبوتاسيوم في دعم نباتات فول الصويا النامية تحت ظروف الشد المائي اجريت تجربة حقلية في محافظة واسط خلال الموسمين الخريفيين 2022 و 2023. استخدم تصميم القطاعات الكاملة(RCBD) بترتيب الالواح المنشقة وبثلاث مكررات استخدمت معاملات الري عند استنفاد30% و45%و60% من الماء الجاهز على الالواح الرئيسة بينما وزعت المعاملات التي شملت A_0(معاملة المقارنة) بذور جافة والرش بالماء المقطر وA1 (نقع البذور بالكلايسين بيتان بتركيز 50 ملي مول لتر$^{-1}$) و A2 (رش حامض السالسلك بتركيز300 ملغم لتر$^{-1}$) وA3 (نقع البذور بالكلايسين بتركيز 50 ملي مول لتر$^{-1}$) والرش بحامض السالسلك بتركيز 300 ملغم لتر$^{-1}$) وA5 (رش البوتاسيوم بتركيز 7.2 غم لتر$^{-1}$) وA5 (نقع البذور بالكلايسين بيتان بتركيز 50 ملي مول لتر$^{-1}$ والرش بالبوتاسيوم بتركيز 7.2 غم لتر$^{-1}$) و A6 جمع المعاملات اعلاه في معاملة واحدة على الالواح الثانوية. اظهرت النتائج عدم وجود فروقا معنوية بين معاملات الري عند استنفاد30 %و45% من الماء الجاهز في صفة أرتفاع النبات والمساحة الورقية ومحتوى الكلورفيل في الموسم الثاني والوزن الجاف للنبات وثباتية الاغشية ونسبة البوتاسيوم وحاصل البذور في كلا الموسمين ، في حين احتوت نباتات معاملة الري عند استنفاد 60%من الماء الجاهز اعلى متوسط من البرولين بلغ (2.7 و 2.8) مايكرومول غم$^{-1}$. اثر التداخل بين معاملات دعم النباتات والري معنويا في صفة ارتفاع النبات والمساحة الورقية ومحتوى الكلورفيل والوزن الجاف للنبات.

الكلمات المفتاحية: اجهاد الجفاف، كميات مياه الري، مضادات النتح، حاصل البذور.

***البحث مستل من اطروحة دكتوراه للباحث الاول**