

Physiological and Enzymatic Responses of Broad Bean to Foliar-Applied Glycine Betaine and α -Tocopherol under Saline Soil Conditions

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Abstract

In light of the economic importance of faba bean, extreme wastage of water, saline soils, and the dominance of traditional water management methods, the presented research transpired in 2025–2026 in fields of the Field Crops Department, Agriculture College - Al-Qasim Green University, Hilla City, Iraq (latitude 32-32.40 North, longitude 45-44.39 East). The latest study aimed to investigate the effects of the response of faba bean to foliar application for glycine betaine and α -tocopherol under saline soil conditions, with four glycine betaine concentrations of 0, 50, 100, and 150 mg L⁻¹ and four α -tocopherol concentrations of 0, 100, 150, and 200 mg L⁻¹ on faba bean. The study proceeded in a randomized complete block design (RCBD) using a split-plot arrangement, with two factors and three replications. The results showed foliar spraying with glycine betaine acid achieved a significant superiority at the concentration of 150 mg L⁻¹, which recorded the highest mean values for total chlorophyll content of 21.816 mg g⁻¹ fresh weight, proline content of 2.304 μ mol g⁻¹ dry weight, crop growth rate of 1.058 g m⁻² day⁻¹, net photosynthesis of 1.078 g m⁻² day⁻¹, catalase enzyme activity of CAT; 9.396 absorbance units min⁻¹ g⁻¹ fresh weight, and superoxide dismutase enzyme activity SOD; 15.922 absorbance units min⁻¹ g⁻¹ fresh weight, compared with the control treatment, which recorded the lowest mean values for the studied traits. Foliar spraying with the antioxidant alpha-tocopherol also produced a positive effect at the concentration of 200 mg L⁻¹, recording the highest mean values for leaf total chlorophyll content of 20.749 mg g⁻¹ fresh weight, crop growth rate of 0.634 g m⁻² day⁻¹, net photosynthesis of 0.822 g m⁻² day⁻¹, catalase enzyme activity CAT; 7.861 absorbance units min⁻¹ g⁻¹ fresh weight, and superoxide dismutase enzyme activity SOD; 15.386 absorbance units min⁻¹ g⁻¹ fresh weight. In this experiment, the 100 mg L⁻¹ treatment group recorded the highest proline content, which reached 1.815 μ mol g⁻¹ dry weight, while the control group had the lowest mean values

Keywords: glycine betaine acid; antioxidant alpha-tocopherol; saline soil - Physiological Characteristics

Introduction

Faba bean (*Vicia faba* L.), is a core global winter legume crop. According to a 2020 study by Muktadir et al. (2020), this crop can provide protein for humans and livestock, and also contains carbohydrates, fiber and other substances, supporting dietary balance [1]. According to 2023 statistics from the Food and Agriculture Organization of the United Nations (FAO), the global area dedicated to cultivating dry broad beans and horse beans totals

approximately 2.6 million hectares, with an aggregate production volume of 5.9 million tons

and an average per-hectare yield of roughly 2.3 tons. This crop holds significant economic and nutritional value in many countries worldwide, particularly in temperate regions [2].

Soil salinity constitutes a predominant constraint on agricultural productivity within arid and semi-arid regions. The accumulation of salts in the root zone causes osmotic stress and

ionic toxicity, which negatively affect plant growth and productivity. Broad bean is considered a moderately salt-sensitive legume crop. Its different growth stages are affected by high salt concentrations, leading to reduced germination percentage, weak vegetative growth, reduced photosynthetic efficiency, and disturbance in the uptake of essential nutrients [3].

Salinity also promotes oxidative stress in broad bean plants through the excessive generation of reactive oxygen species, which leads to damage to cell membranes, proteins, and enzymes. Consequently, the number and weight of pods and seeds decrease, which is reflected in the total yield. With the increasing severity of these negative effects, there has been a need to use modern methods to alleviate salinity damage. Among the most important methods are foliar treatments with growth-regulating or protective substances [4].

Foliar spraying with glycine betaine is considered one of the effective methods for improving plant tolerance to salt stress. It acts as a compatible solute that contributes to maintaining osmotic balance within cells and protecting proteins and biological membranes. It also improves photosynthetic efficiency and reduces stress effects. In addition, it enhances the plant's ability to retain water and regulate ion uptake, thereby reducing the toxicity resulting from sodium and chloride accumulation [5].

Alpha-tocopherol, also known as vitamin E, is a non-enzymatic antioxidant with an important role in protecting plant cells from

oxidative damage caused by salt stress through the inhibition of free radicals and reduction of membrane lipid damage. Foliar spraying with this compound helps improve membrane stability and increase the activity of defence systems within the plant. [6].confirmed that this variable promotes plant growth and increases yield.

This study proposes that the combined use of glycine betaine and α -tocopherol is a promising solution to alleviate the damage that soil salinity causes to faba beans: the former regulates osmotic balance, while the latter mitigates oxidative stress. This ultimately leads to the improvement of physiological, morphological, and productive traits. Therefore, studying the effect of these treatments is highly important for developing sustainable agricultural techniques to increase broad bean productivity under salt-stress conditions.

The objectives and importance of this study were:

1. To stimulate broad bean productivity through foliar spraying with glycine betaine and α -tocopherol, as well as to study their effectiveness in reducing the effect of soil salinity and increasing plant tolerance to it.
2. To study the effect of the two-way interactions of foliar spraying with concentrations of glycine betaine and α -tocopherol on the morphological, physiological, and productive traits of this crop, in order to achieve distinguished growth and yield, quantitatively and qualitatively, in broad bean.

Materials and Methods

A field experiment was conducted during the 2025–2026 winter season at the experimental fields of the Department of Crops, College of Agriculture, University of Al-Qasim Green, situated in the southern region of Babylon Governorate (latitude 32.40° N, longitude 44.39° E). The objective of the study was to evaluate the physiological effects of foliar spraying with glycine betaine and the antioxidant alpha-tocopherol on the

physiological characteristics of the faba bean crop cultivated under saline soil conditions.

Before sowing, five soil samples were collected at random from different positions within the experimental field at a depth of 0–30 cm. The individual samples were homogenized to produce a composite sample, which was subsequently sun-dried with periodic turning, milled, and sieved through a 2-mm mesh. Prior to planting, the physicochemical properties of the soil were evaluated using standard protocols

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[7]. Analyses were carried out at the Soil and Water Analysis Laboratory, Babylon Agriculture Directorate, Al-Muradiya Research Station., as shown in Table 1.

Table 1. Chemical and physical properties of the experimental soil and irrigation water before planting

Soil texture	Soil separates (%)			Organic matter OM (%)	Available nutrients (mg kg ⁻¹)			Electrical conductivity EC (dS m ⁻¹)	pH	Sample
	Sand	Silt	Clay		K	P	N			
Clay loam	267	338	395	0.74	130.49	8.16	32.48	7.11	7.78	Soil
-	-	-	-	-	8.25	5.21	17.11	1.69	7.13	Irrigation water

The experiment was conducted utilizing a randomized complete block design (RCBD) with a factorial arrangement. This experiment set two core independent variables. Glycine betaine was tested at four concentrations: 0, 50, 100, and 150 mg/L, while the antioxidant α -tocopherol was applied as a spray at four concentrations: 0, 100, 150, and 200 mg/L.

In this study, the entire experimental field was divided into 3 blocks, with a 1.5-m spacing reserved between blocks to serve as irrigation canals and work access paths. Each block contained 16 experimental treatments, with an 80-cm spacing left between treatments to prevent pesticide spray drift. Each individual experimental unit measured 3 × 3 m, and within each unit, the crop's in-row plant spacing was 0.25 m and inter-row spacing was 0.5 m. The crop used in this experiment is a Spanish cultivated variety, which was planted on October 10, 2025 in saline soil with an EC value of 7 dS. Two foliar spray treatments were carried out: the first at the 4-6 leaf stage, 30 days after planting, and the second at the pre-flowering stage, 15 days after the first spray application. During the field experiment

conducted for this study, pesticides were applied in the early morning at each specified growth stage of the crops, using a 16-liter knapsack sprayer. Al-Zahi spreader was added to reduce water surface tension to ensure the entire plant was fully wetted.

Meanwhile, soil and cultivation management tasks such as seedling supplementation and seedling thinning were carried out as needed. One week after completing the spraying operations, fresh and dry leaves and plant samples were collected at the beginning of flowering for laboratory analyses of the studied traits. Following data collection, the results were tabulated and subjected to an analysis of variance (ANOVA) using GenStat software. Subsequently, the least significant difference (LSD) test was employed at a 0.05 significance level to compare the arithmetic means.

Physiological Characteristics

- 1- Leaf Chlorophyll Content (mg/g fresh weight)
- 2- Leaf Proline Amino Acid Content (μmol/g dry weight)

- 3- Crop Growth Rate ($\text{g m}^{-2} \text{y}^{-1}$)
- 4- Net Photosynthesis ($\text{g m}^{-2} \text{y}^{-1}$)
- 5- Enzyme Activity Assessment
- 6- Catalase (CAT) Enzyme Activity Assessment

- 7- Superoxide Dispersion (SOD) Enzyme Activity Assessment

Results and Discussion

Leaf chlorophyll content (mg g^{-1} fresh weight)

The results revealed a significant increase in total leaf chlorophyll content among the concentrations of glycine betaine (Table 2). Foliar spraying at a rate of 150 mg L^{-1} achieved the highest mean of $21.816 \text{ mg } 100 \text{ g}^{-1}$ fresh weight, compared with control treatment (without spraying), which achieved the least average of $16.211 \text{ mg } 100 \text{ g}^{-1}$ fresh weight. The increase in total leaf chlorophyll content resulting from foliar spraying with glycine betaine may be attributed to its role in maintaining chloroplast integrity and cell membrane stability, in addition to reducing oxidative stress and enhancing the efficiency of the antioxidant system. This limits chlorophyll degradation and maintains its continuous formation and accumulation in the leaves. This is positively reflected in photosynthetic efficiency and increased total chlorophyll content. This result agrees with that reported by Singh et al. [8].

It is also observed from the same table that foliar application of the antioxidant alpha-tocopherol was superior in total leaf chlorophyll content. Application at a concentration of 200 mg L^{-1} yielded the highest mean of $20.749 \text{ mg } 100 \text{ g}^{-1}$ fresh weight, whereas the untreated control exhibited the lowest mean of $17.624 \text{ mg } 100 \text{ g}^{-1}$ fresh weight. The observed enhancement in total leaf chlorophyll content following alpha-tocopherol application is likely attributable to its capacity to mitigate the adverse effects of salinity stress, through improving photosynthetic efficiency and protecting chlorophyll pigments from oxidative degradation. This result agrees with that reported by Khalil et al. [9].

With regard to the significant interaction, The treatment of glycine betaine at 150 mg L^{-1} combined with alpha-tocopherol at 200 mg L^{-1} produced the greatest chlorophyll value ($26.115 \text{ mg } 100 \text{ g}^{-1}$ fresh weight), compared with the control treatment (without spraying) of glycine betaine combined with alpha-tocopherol at 150 mg L^{-1} , which recorded the least average of $14.809 \text{ mg } 100 \text{ g}^{-1}$ fresh weight.

Table 2. Effect of foliar application of glycine betaine and α -tocopherol on total chlorophyll content in the leaves ($\text{mg } 100 \text{ g}^{-1}$ fresh weight) of broad bean plants under saline soil conditions.

Mean glycine betaine	Alpha-tocopherol rate (mg L^{-1})				Glycine betaine rate (mg L^{-1})
	200	150	100	0	
16.211	18.787	14.809	15.207	16.04	0
18.169	16.909	16.971	20.996	17.80	50
19.683	21.186	24.954	15.555	17.03	100
21.816	26.115	20.674	20.859	19.61	150
0.5421	LSD				(0.05)

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine rate (mg L ⁻¹)	betaine
		200	150	100	0		
		20 749	19 352	18 154	17 62	Mean	alpha-
		I.SD (0.05)				0.5421	

Leaf content of the amino acid proline (μmol g⁻¹)

Results presented in Table 3 shows significant differences between glycine concentrations. The lowest average concentration (1.433 μmol g⁻¹) was obtained at 150 mg L⁻¹, compared to the budding plant treatment which achieved the highest average concentration (2.304 μmol g⁻¹). The lower proline content in unsprayed plants compared to well-treated plants with glycine betaine may be attributed to the plant's physiological density when exposed to salinity, as the concentration of salts in the area leads to a decrease in the soil's osmotic potential. This hinders water absorption and disrupts ionic balance due to the accumulation of sodium and chloride ions within plant tissues. In response, the plant begins to accumulate large quantities of proline to maintain cellular osmotic balance, minimize water loss, and preserve turgor pressure. (20) demonstrated that proline is a key compatible solute accumulating in plants under salinity and drought conditions, contributing to osmotic adjustment and protecting proteins and cell membranes from stress-induced damage.

Table also shows significant differences between the concentrations of the antioxidant alpha-tocopherol. The 100 mg L⁻¹ concentration achieved the lowest mean concentration of 1.459 μmol g⁻¹ compared to

the control treatment, which achieved the highest mean concentration of 1.815 μmol g⁻¹. The significant increase in proline content in plants not sprayed with alpha-tocopherol is attributed to their exposure to greater intensity of salt and oxidative stress. The absence of alpha-tocopherol leads to increased accumulation of reactive oxygen species (ROS) and lipid peroxidation in the plant. ...cell membranes, thereby stimulating the plant to increase the synthesis of proline—one of the key compatible solutes that accumulate to counter adverse environmental conditions. Proline functions to maintain cellular osmotic balance, protect proteins and cell membranes, and stabilize enzyme activity, in addition to its role in scavenging free radicals; consequently, elevated proline concentrations in unsprayed plants indicate increased stress severity rather than an improvement in the plant's physiological status (21).

The results presented in the table also revealed a significant interaction effect among the spray treatments; specifically, the combined application of glycine betaine (150 mg L⁻¹) and alpha-tocopherol (200 mg L⁻¹) yielded the lowest mean value (0.867 μmol g⁻¹), whereas the control treatment recorded the highest mean value (2.543 μmol g⁻¹).

betaine and α-tocopherol on leaf proline content (μmol g⁻¹) of broad bean plants under saline soil conditions.

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)
		200	150	100	0	
2 304		2 543	2 127	2 153	2 39	0
1 541		1 19	1 683	1 857	1 43	50
1 502		1 75	1 49	1 623	1 14	100
1 433		1 667	1 573	1 627	0 86	150
0 2038			0 4076	I.SD (0.05)		
		1 788	1 718	1 815	1 45	Mean
		I.SD (0.05)			0 2038	alpha-

Crop Growth Rate (g m⁻² day⁻¹)

As indicated in Table 4, significant differences were observed among the various concentrations of glycine betaine. Notably, the 150 mg L⁻¹ concentration yielded the highest mean value of 1.058 g m⁻² day⁻¹ relative to the control treatment (without spraying), which achieved the least mean of 0.075 g m⁻² day⁻¹. The increase in crop growth rate resulting from foliar spraying with glycine betaine may be attributed to its role in improving photosynthetic efficiency through increasing chlorophyll content and maintaining plant water content, which leads to increased production and accumulation of dry matter in vegetative and reproductive parts. Glycine betaine also contributes to protecting cell membranes and enzymatic systems from oxidative damage and improving the efficiency of metabolic processes. This is reflected in an increased dry matter accumulation rate and a higher crop growth rate. This result is consistent with the findings of. [12].

The results also revealed significant differences among the rates of the antioxidant alpha-tocopherol. The rate of 200 mg L⁻¹ achieved the highest mean of 0.634 g m⁻² day⁻¹, compared to control treatment (without spraying), which achieved the least mean of 0.214 g m⁻² day⁻¹. The improvement in crop growth rate when plants were treated with alpha-tocopherol may be attributed to its role in protecting cell membranes from damage caused by oxidative stress and reducing lipid peroxidation. This contributed to maintaining cell integrity and the efficiency of vital processes within the plant. This was positively reflected in plant tissue activity and increased dry matter accumulation, which contributed to improving crop growth rate. This result agrees with that reported [13].

The results revealed a significant interaction between study factors. The greatest crop growth rate (1.618 g m⁻² day⁻¹) was observed when 150 mg L⁻¹ glycine betaine was combined with 200 mg L⁻¹ α-tocopherol. The untreated combination gave the lowest value (0.017 g m⁻² day⁻¹).

Table 4. Effect of foliar application of glycine betaine and α-tocopherol on crop growth rate (g m⁻² day⁻¹) of broad bean plants under saline soil conditions.

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)
		200	150	100	0	
0 075		0 17	0 077	0 037	0 01	0

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)
		200	150	100	0	
0.116		0.21	0.119	0.099	0.03	50
0.282		0.536	0.3	0.274	0.01	100
1.058		1.618	0.948	0.883	0.78	150
0.1222			0.2444	I.S.D (0.05)		
		0.634	0.361	0.323	0.21	Mean
		I.S.D (0.05)		0.1222		
						alpha-

4. Net Photosynthesis (g m⁻² day⁻¹)

Results presented in Table 5 implies that net photosynthesis responded significantly to foliar spray of glycine betaine. The rate of 150 mg L⁻¹ yielded the highest mean value of 1.078 (g m⁻² day⁻¹), relevant to the control treatment (without spraying), which achieved the least average of 0.371. (g m⁻² day⁻¹), This improvement in the net photosynthesis rate may be associated with the role of glycine betaine in improving leaf stomatal characteristics and increasing stomatal conductance. This led to increased CO₂ entry into leaf tissues and improved photosynthetic efficiency. In addition, it contributed to protecting the photosynthetic apparatus and cell membranes from oxidative damage caused by stress, which helped maintain photosynthetic processes at higher efficiency. This result agrees with that reported. [14].

The results of Table 5 also showed significant differences among the rates of the antioxidant alpha-tocopherol. The highest net photosynthesis rate mean (0.822) (g m⁻² day⁻¹) was obtained with 200 mg L⁻¹ α-

tocopherol, relative to control treatment (without spraying), which achieved the least average of 0.522(g m⁻² day⁻¹),

The significant improvement in net photosynthesis following alpha-tocopherol treatment could be attributed to its role in protecting photosynthetic pigments and thylakoid membranes from oxidation, thereby maintaining chlorophyll and carotenoid contents. Furthermore, it augmented antioxidant enzymatic activity while attenuating the accumulation of H₂O₂ and MDA. This maintained the efficiency of the photosynthetic apparatus and the continuation of CO₂ fixation processes, which was positively reflected in net photosynthesis and growth. This result agrees with that reported. [15].

The results revealed a significant interaction between study factors. Foliar spraying with glycine betaine at a rate of 150 mg L⁻¹ combined with alpha-tocopherol at a rate of 200 mg L⁻¹ achieved The greatest crop growth rate of 1.527 (g m⁻² day⁻¹), relative to the control treatment (without spraying), which achieved the least average of 0.233.

Table 5. Effect of foliar application of glycine betaine and α-tocopherol on net photosynthesis(g m⁻² day⁻¹), of broad bean plants under saline soil conditions.

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)
		200	150	100	0	
0.371		0.467	0.423	0.360	0.23	0
0.565		0.613	0.597	0.550	0.50	50
0.658		0.680	0.660	0.653	0.64	100
1.078		1.527	1.183	0.883	0.71	150

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)
		200	150	100	0	
0.0798			0.1596	I.S.D (0.05)		
		0.822	0.716	0.612	0.52	Mean
		I.S.D (0.05)			0.0798	alpha-

Catalase Enzyme Activity (CAT) (absorbance units min⁻¹ g⁻¹)

Results presented in Table 5 implies that net photosynthesis responded significantly to foliar spray of glycine betaine. The rate of 150 mg L⁻¹ yielded the highest mean value of 9.396 μ mol g⁻¹ (g m⁻² day⁻¹), relevant to the control treatment (without spraying), which achieved the least average of 5.683 absorbance units min⁻¹ g⁻¹. The significant increase in catalase enzyme (CAT) activity following foliar spraying with glycine betaine may be attributed to its role in activating the antioxidant system within the plant. It increases the plant's capacity to remove hydrogen peroxide and free radicals formed under stress conditions, thereby reducing oxidative damage, maintaining cell membrane integrity, and improving plant physiological performance. This result agrees with that reported. [16].

The results also revealed significant differences in catalase enzyme activity (absorbance units min⁻¹ g⁻¹) following foliar application with α -tocopherol at a rate of 200

mg L⁻¹. This study recorded a measurement of 7.861 absorbance units min⁻¹ g⁻¹ for the spray treatment group, and 6.287 for the blank control group. This finding corroborates the effectiveness of the tested treatment.

This study found that treatment with α -tocopherol, a non-enzymatic antioxidant, can increase the activity of catalase (CAT). This in turn strengthens plants' antioxidant defense systems, enhances their ability to detoxify H₂O₂, reduces ROS accumulation, alleviates oxidative damage, and maintains the integrity of cell membranes. This result agrees with that reported [17].

Furthermore, the data presented in Table 6 reveal a significant interaction effect between the foliar spray treatments. Specifically, the combined application of glycine betaine (150 mg L⁻¹) and the antioxidant alpha-tocopherol (200 mg L⁻¹) yielded the maximum mean value of 11.286 absorbance units min⁻¹ g⁻¹, whereas the control treatment produced the minimum mean value of 4.948 absorbance units min⁻¹ g⁻¹.

Table 6. Effect of foliar application of glycine betaine and α -tocopherol on catalase enzyme activity (CAT; absorbance units min⁻¹ g⁻¹ fresh weight) of broad bean plants under saline soil conditions.

Mean betaine	glycine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)
		200	150	100	0	
5.683		5.997	5.989	5.797	4.94	0
6.599		6.547	6.922	6.923	6.00	50
7.148		7.616	6.43	7.119	7.42	100
9.396		11.286	9.937	9.592	6.76	150
0.5263			1.0527	I.S.D (0.05)		
		7.861	7.32	7.358	6.28	Mean
		I.S.D (0.05)			0.5263	alpha-

6. Superoxide Dismutase Enzyme Activity (SOD) (absorbance units min⁻¹ g⁻¹ fresh weight)

Results presented in Table 7 implies a significant differences among the rates of glycine betaine. The rate of 150 mg L⁻¹ yielded the highest average value of 15.922 absorbance units min⁻¹ g⁻¹, relevant to the control treatment (without spraying), which achieved the least average of 10.154 absorbance units min⁻¹ g⁻¹. The increase in superoxide dismutase enzyme (SOD) activity as a result of foliar spraying with glycine betaine may be attributed to its role in activating the antioxidant defence system in the plant, which enhances the ability of cells to eliminate superoxide radicals produced under stress conditions. Glycine betaine also contributes to maintaining the stability of cellular membranes and proteins and reducing oxidative damage, thereby increasing the efficiency of the enzyme in protecting the plant from damage caused by stress. This result agrees with that reported. [18].

results also revealed a significant increase in superoxide dismutase enzyme activity following foliar spraying with α -tocopherol at a rate of 200 mg L⁻¹, this treatment achieved the highest average of 15.386 absorbance units min⁻¹ g⁻¹, in relative to control treatment, which achieved the least average of 12.266 absorbance

units g⁻¹. The increase in superoxide dismutase enzyme (SOD) activity following α -tocopherol treatment under saline conditions may be attributed to its role as an antioxidant that reduces oxidative stress resulting from the accumulation of sodium ions (Na⁺) and the stimulation of reactive oxygen species (ROS) formation. α -tocopherol reduces lipid peroxidation and enhances cell membrane stability, which leads to improved metabolic balance within the cell and activation of the antioxidant defence system. This consequently increases the efficiency of the SOD enzyme in eliminating superoxide radicals and converting them into less harmful compounds, which is positively reflected in plant tolerance to salt stress. The results of the faba bean experiment conducted in this study under saline-alkali soil conditions are consistent with the conclusions reported [19]. Relevant data are presented in Table 7, which summarizes the effects of two foliar spray reagents, betaine and α -tocopherol, on the SOD activity of faba bean. A significant interactive effect exists between the different treatments. The mean activity of the 150 mg/L dual-reagent combination group was 18.969, while that of the control group was only 9.33. All units are uniformly expressed as absorbance unit·min⁻¹·g⁻¹.

Table 7. Influence of foliar-applied glycine betaine and α -tocopherol on the superoxide dismutase (SOD) enzyme activity (absorbance units min⁻¹ g⁻¹ fresh weight) of broad bean plants cultivated under saline soil conditions.

Mean glycine betaine	Alpha-tocopherol rate (mg L ⁻¹)				Glycine betaine rate (mg L ⁻¹)	
	200	150	100	0		
10 154	9 93	11 327	10 029	9 33	0	
13 915	18 174	13 856	11 877	11 7	50	
15 662	15 549	16 659	12 183	18 2	100	
15 922	17 889	18 969	14 976	11 8	150	
0.5617		1.1233	I.SD (0.05)			
	15 386	15 203	12 799	12 2	Mean	alpha-
	I.SD (0.05)			0.5617		

Conclusions

This study confirms that for faba beans grown in saline-alkali soil, foliar application of 150 mg·L⁻¹ glycine betaine, whether applied alone or in combination with 200 mg·L⁻¹ α-tocopherol, can optimize the crop's physiological and enzymatic responses through three mechanisms: promoting osmotic

homeostasis, maintaining photosynthetic machinery, and upregulating antioxidant defense. This is a high-efficiency intervention to boost salt tolerance. Collectively, these physiological adaptations significantly enhance the plants' resilience to salt stress, thereby facilitating superior growth performance and overall productivity

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