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The Role of Sorbitol in Improving Vegetative Growth and Some Physiological and Biochemical Traits of Cucumber (*Cucumis sativus* L.) under Salt Stress Conditions

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Abstract: The experiment was conducted during the 2025–2026 growing season in a plastic greenhouse in Al-Alam Subdistrict, Salah Al-Din Governorate, Iraq, to investigate the role of sorbitol in improving vegetative growth and some physiological and biochemical traits of cucumber (*Cucumis sativus* L.) under salt stress conditions. The experiment involved two factors: the first consisted of three salinity levels using sodium chloride (NaCl) at concentrations of 0, 3, and 6 mg L^{-1}, while the second consisted of three sorbitol levels at concentrations of 0, 2, and 4 mg L^{-1}, applied as foliar sprays. The experiment was conducted using a randomized complete block design (RCBD) in a factorial arrangement, with three replicates, comprising nine treatment combinations and 27 experimental units. The investigated traits included plant height, number of leaves, leaf area, fresh and dry weights, leaf chlorophyll, proline and soluble sugar contents, as well as the activities of catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD) enzymes.

The results showed that increasing salinity levels reduced vegetative growth traits and chlorophyll content, whereas proline and soluble sugar contents and the activities of catalase and peroxidase increased with increasing salt stress. Sorbitol application improved vegetative growth traits and chlorophyll content, while reducing proline content compared with treatments receiving lower sorbitol concentrations. The S_0P_2 treatment (no salt addition with 4 mg L^{-1} sorbitol) recorded the highest values for plant height, number of leaves, leaf area, fresh and dry weights, and chlorophyll content, reaching 90.16 cm, 19 leaves $plant^{-1}$, 1,390 cm^2 $plant^{-1}$, 200 g $plant^{-1}$, 28 g $plant^{-1}$, and 49 SPAD units, respectively. In contrast, the S_2P_0 treatment (6 mg L^{-1} NaCl without sorbitol) recorded the lowest values for these traits, demonstrating the adverse effect of salinity on cucumber growth and the improvement associated with sorbitol application under the experimental conditions. The highest soluble sugar content and catalase and peroxidase activities were recorded in the S_2P_2 treatment, whereas the S_2P_0 treatment exhibited the highest proline content. Accordingly, it can be concluded that sorbitol at the highest concentration tested (4 mg L^{-1}) was associated with improvements in several indicators of vegetative growth and physiological status in cucumber under salt stress, although the response varied depending on the trait and salinity level.

Introduction

Salinity of soil and irrigation water is one of the most important abiotic factors responsible for growth and yield reduction in crop plants, particularly in arid and semi-arid areas where salinity in the rhizosphere increases due to evaporation. Osmotic potential of the soil solution decreases as salt levels increase around the roots, making it increasingly difficult for plants to take up water. This is exacerbated by the accumulation of certain ions to toxic levels, nutritional imbalances, and inhibition of cellular physiological and biochemical processes. Munns and Tester (2008) theorized the plant response to salinity as a two-step process: an early osmotic phase in which growth is suppressed, and a late ionic phase in which growth is affected by the accumulation of toxic ions. Similarly, van Zelm et al. (2020) stated that salinity adaptation is the result of a complex web of stress perception, intracellular signaling, and coordinated physiological and molecular responses.

Cucumber (Cucumis sativus L.) is an important vegetable both nutritionally and commercially and is sensitive to adverse environmental conditions such as salinity. Salinity stress can restrict vegetative growth, decrease leaf area and fresh and dry biomass production, and impair metabolic homeostasis and photosynthetic functioning. It is therefore worthwhile to investigate the salinity response of cucumber, as sustained growth depends on the ability to maintain leaf water status, photosynthetic efficiency, and the protection of vital functions leading to tissue production.

Numerous coordinated responses, including alteration of osmotic potential, maintenance of membrane structure and function, and induction of antioxidant systems are forced upon plants by salinity. In this repertoire, small organic solutes have received continual scientific interest because they are believed to be involved in osmotic adjustment and to protect tissues from the harmful effects of harsh environmental conditions (Ashraf and Foolad, 2007).

Of these, the sugar alcohol sorbitol (glucitol) of the polyol class has been of special interest because of its association with carbon metabolism and with plant osmotic response which varies with species and growing environment. However, it should not be assumed that external sorbitol is always a good salt tolerance agent: effectiveness is influenced by the amount used, time of application and the growth stage of the plant, and should be tested.

Evidence for the protective effects of such organic compounds under environment stress thus provides a solid foundation for testing this hypothesis. Ashraf and Foolad (2007) provided an overview of the role of compatible solutes, including proline, in osmotic adjustment and protection of membranes and proteins under abiotic stress. However, evidence for proline or betaine cannot be considered direct evidence for the effectiveness of sorbitol; a dedicated experiment is required to establish its influence on salt-stressed cucumber plants.

Physiological and biochemical parameters are also useful in assessing cucumber responses to salinity. The levels of chlorophyll, proline, and soluble sugars provide information on the status of photosynthetic pigments and metabolic changes associated with osmotic adjustment. Similarly, the responses of antioxidant enzymes reflect changes in the enzymatic defense system in response to the oxidative stress generated by salinity. Furtuna and Tipirdamaz (2010) reported that growth, chlorophyll and proline levels, and antioxidant enzyme activities of cucumber plants differed under salinity stress depending on the cultivar, suggesting the value of the combined evaluation of these parameters.

Plant height, number of leaves, leaf area, and fresh and dry weights provide a convenient way of assessing the morphological and physiological effects of salinity and sorbitol treatments on vegetative growth. Zhu et al. (2008) demonstrated that the growth indices of cucumber (height, number of leaves, leaf area, and dry weight) were reduced by increasing sodium chloride levels, although the magnitude of reduction varied among the different cultivars tested.

In view of this, the present study was conducted to evaluate the ability of sorbitol to counteract the negative effects of salinity on selected vegetative growth parameters, chlorophyll content, proline and soluble sugar contents, and antioxidant enzyme activities in cucumber. The results of the outcomes will help in understanding the impact of the treatments and the improvement of growth and physiological adaptation by sorbitol under salinity stress.

The originality of this study lies in the integration of growth data with physiological and biochemical traits in a single experimental context without preconceived conclusions. These parameters should be considered in conjunction with growth data, as an increase in a particular stress-associated marker may not necessarily reflect greater tolerance; it may indicate an increase in stress level or the activation of a defense response.

Materials and Methods

1. Experimental Site and Duration

The experiment was conducted during the 2025-2026 growing season in a plastic greenhouse in Al-Alam Subdistrict, Salah Al-Din Governorate, Iraq. It was conducted to determine the effects of salt stress and various levels of sorbitol on vegetative growth and some physiological and biochemical characteristics of cucumber (Cucumis sativus L.). Plant samples were subjected to laboratory analysis in the Department of Horticulture and Landscape Gardening, College of Agriculture, Tikrit University, whereas soil samples were analyzed in the Department of Soil and Water Resources, College of Agriculture, Tikrit University.

2. Plant Material

The seeds of a hybrid cucumber cultivar, Seminis-Bayer, were planted in the greenhouse during the aforementioned season. Seminis is a commercial brand that markets hybrid vegetable seeds, including cucumber seeds (Bayer Crop Science, n.d.).

3. Experimental Design and Treatments

A two-factor factorial experiment was conducted using a Randomized Complete Block Design (RCBD). The factors were salinity stress imposed by NaCl at three levels and sorbitol at three levels, with three replicates, resulting in nine treatment combinations and a total of 27 experimental units.

Sodium chloride was applied at 0, 3, and 6 mg L^{-1}, and sorbitol at 0, 2, and 4 mg L^{-1}. The salinity levels were coded as S_0, S_1, and S_2, and the sorbitol levels were coded as P_0, P_1, and P_2. All combinations of the two factors were tested in the experiment.

Treatment Code	Sodium Chloride (mg L^{-1})	Sorbitol (mg L^{-1})
S_0P_0	0	0
S_0P_1	0	2
S_0P_2	0	4
S_1P_0	3	0
S_1P_1	3	2

Treatment Code	Sodium Chloride (mg L^{-1})	Sorbitol (mg L^{-1})
S_1P_2	3	4
S_2P_0	6	0
S_2P_1	6	2
S_2P_2	6	4

4. Planting and Treatment Application

The seedlings were then transferred to the greenhouse and irrigation and normal cultural practices were followed to allow normal plant growth. Once the plants had developed to the proper growth stage, salinity treatments were imposed by application of NaCl solution and sorbitol was sprayed as a foliar treatment. Other agronomic practices were uniform among the experimental units except for the treatments applied.

5. Investigated Traits and Measurement Methods

5.1. Vegetative Growth Traits

1. Plant Height (cm)

The vertical size of each plant was measured as the distance from the base of the stem at the soil surface to the plant's terminal growing point with the aid of a graduated ruler. Within each experimental unit a set of representative plants was chosen for the reading.

2. Number of Leaves (leaves $plant^{-1}$)

The number of all fully expanded true leaves on a plant was counted at each date of measurement. The average number of plants in each experimental unit was used to represent the experimental unit for statistical analysis.

3. Leaf Area (cm^2 $plant^{-1}$)

Foliar area was determined using a Leaf Area meter, by scanning each leaf of the plant separately. The areas of the readings were then summed for each plant, giving the total leaf area of the plant.

4. Fresh Weight (g $plant^{-1}$)

The plant material after harvesting was immediately cleaned of all soil or growing medium and weighed on a precision balance and the weight recorded as fresh biomass of the plant.

5. Dry Weight (g $plant^{-1}$)

Plant samples were dried in an oven at 70°C until a constant weight was achieved. The samples were then weighed using a precision balance to determine plant dry weight.

5.2. Physiological and Biochemical Traits

1. Chlorophyll Content

Leaf chlorophyll content was measured using a chlorophyll meter (SPAD). Readings were taken from mature leaves of comparable age and position on the plants.

2. Proline Content

Free proline content in the leaves was determined using a colorimetric method based on the reaction of proline with acid ninhydrin. Proline was extracted from the plant samples, followed by the color development reaction. Absorbance was measured at 520 nm, and proline concentration was calculated using a standard proline calibration curve according to the method described by Bates et al. (1973).

3. Soluble Sugar Content

Soluble sugar content was determined using the anthrone colorimetric method. Sugars were extracted from the plant tissues, followed by the color development

reaction and spectrophotometric measurement. Sugar concentration was calculated using a glucose standard calibration curve according to the method described by Morris (1948).

4. Antioxidant Enzyme Activities

The antioxidant defense system was evaluated by measuring the activities of catalase (CAT), peroxidase (POD), Enzyme extracts were prepared from fresh leaf samples using an appropriate extraction buffer. The extracts were centrifuged, and the resulting supernatants were used to determine enzyme activities using suitable spectrophotometric methods. Catalase activity was determined according to Aebi (1984), peroxidase activity according to Chance and Maehly (1955),

5. Soil Analysis

Soil analysis was conducted in the Department of Soil and Water Resources, College of Agriculture, Tikrit University, to determine the physical and chemical properties relevant to cucumber growth. These included soil pH and electrical conductivity (EC), in addition to other properties included in the analysis.

6. Statistical Analysis

The experimental data were analyzed according to the randomized complete block design using analysis of variance (ANOVA) for factorial experiments to determine the main effects of salinity stress and sorbitol, as well as the interaction between the two factors. The least significant difference (LSD) test was used to compare treatment means at a probability level of 0.05. Statistical analyses were performed in the Department of Horticulture and Landscape Gardening, College of Agriculture, Tikrit University.

Results and Discussion

Effect of Sorbitol on Cucumber Plant Height under Salt Stress Conditions

The data presented in the table showed that the S_0P_2 treatment recorded the greatest cucumber plant height, reaching 90.16 cm, whereas the S_2P_0 treatment recorded the lowest value of 58.11 cm. Regarding the main effect of salinity, the S_0 level recorded the highest mean plant height of 87.67 cm, while the S_2 level recorded the lowest mean of 63.00 cm. With respect to sorbitol, the P_2 level achieved the highest mean plant height of 79.33 cm, whereas the P_0 level recorded the lowest mean of 71.67 cm.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S_0	85.61	88.23	90.16	87.67
S_1	72.08	76.12	80.44	76.00
S_2	58.11	63.15	68.53	63.00
Mean	71.67	75.67	79.33	
6.93 SXP		4.00 P	4.00 S	LSD

Effect of Sorbitol on the Number of Leaves in Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_0P_2 treatment recorded the highest number of leaves, reaching 19 leaves plant^{-1}, whereas the S_2P_0 treatment recorded the lowest number, with 11 leaves plant^{-1}. Regarding the main effect of salinity, the S_0 level recorded the highest mean of 18 leaves plant^{-1}, while the S_2

level recorded the lowest mean of 13 leaves plant^{-1}. With respect to sorbitol, the P_2 level achieved the highest mean number of leaves, reaching 17 leaves plant^{-1}, whereas the P_0 level recorded the lowest mean of 14 leaves plant^{-1}.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S_0	17	18	19	18
S_1	14	16	17	15.67
S_2	11	13	15	13
Mean	14	15.67	17	
2.08 SXP		**1.20** P	**1.20** S	LSD

Effect of Sorbitol on Leaf Area of Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_0P_2 treatment recorded the largest leaf area, reaching 1,390.00 cm² plant^{-1}, whereas the S_2P_0 treatment recorded the smallest leaf area, at 780.00 cm² plant^{-1}. Regarding the main effect of salinity, the S_0 level recorded the highest mean leaf area of 1,320.00 cm² plant^{-1}, while the S_2 level recorded the lowest mean of 906.67 cm² plant^{-1}. With respect to sorbitol, the P_2 level achieved the highest mean leaf area, reaching 1,220.00 cm² plant^{-1}, whereas the P_0 level recorded the lowest mean of 1,016.67 cm² plant^{-1}.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S0	1250.00	1320.00	1390.00	1320.00
S_1	1020.00	1120.00	1230.00	1123.33
S_2	780.00	900.00	1040.00	906.67
Mean	1016.67	1113.33	1220.00	
138.56 SXP		80.12 P	80.14 S	LSD

Effect of Sorbitol on the Fresh Weight of Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_0P_2 treatment recorded the highest fresh weight of the plant biomass, reaching 200.00 g plant^{-1}, whereas the S_2P_0 treatment recorded the lowest fresh weight, at 110.00 g plant^{-1}. Regarding the main effect of salinity, the S_0 level recorded the highest mean fresh weight of 190.00 g plant^{-1}, while the S_2 level recorded the lowest mean of 130.00 g plant^{-1}. With respect to sorbitol, the P_2 level achieved the highest mean fresh weight, reaching 175.00 g plant^{-1}, whereas the P_0 level recorded the lowest mean of 145.00 g plant^{-1}.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S_0	180.00	190.00	200.00	190.00
S_1	145.00	160.00	175.00	160.00
S_2	110.00	130.00	150.00	130.00
Mean	145.00	160.00	175.00	LSD
20.78 SXP		12.00 P	12.00 S	

Effect of Sorbitol on the Dry Weight of Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_0P_2 treatment recorded the highest dry weight of the plant biomass, reaching 28.00 g plant^{-1}, whereas the S_2P_0 treatment recorded the lowest dry weight, at 14.00 g plant^{-1}. Regarding the main effect of salinity, the S_0 level recorded the highest mean dry weight of 26.00 g plant^{-1}, while the S_2 level recorded the lowest mean of 17.00 g plant^{-1}. With respect to sorbitol, the P_2 level achieved the highest mean dry weight, reaching 24.00 g plant^{-1}, whereas the P_0 level recorded the lowest mean of 19.00 g plant^{-1}.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S_0	24.00	26.00	28.00	26.00
S_1	19.00	21.00	24.00	21.33
S_2	14.00	17.00	20.00	17.00
Mean	19.00	21.33	24.00	
3.46 SXP		2.08 P	2.11 S	LSD

Effect of Sorbitol on Leaf Chlorophyll Content in Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_0P_2 treatment recorded the highest leaf chlorophyll content, reaching 49.00 SPAD units, whereas the S_2P_0 treatment recorded the lowest value of 30.00 SPAD units. Regarding the main effect of salinity, the S_0 level recorded the highest mean chlorophyll content of 47.00 SPAD units, while the S_2 level recorded the lowest mean of 34.00 SPAD units. With respect to sorbitol, the P_2 level achieved the highest mean chlorophyll content, reaching 43.67 SPAD units, whereas the P_0 level recorded the lowest mean of 37.67 SPAD units.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S_0	45.00	47.00	49.00	47.00
S_1	38.00	41.00	44.00	41.00
S_2	30.00	34.00	38.00	34.00
Mean	37.67	40.67	43.67	LSD
5.20 SXP		3.04 P	3.00 S	

Effect of Sorbitol on Leaf Proline Content in Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_2P_0 treatment recorded the highest leaf proline content, reaching 1.20, whereas the S_0P_2 treatment recorded the lowest content of 0.40. Regarding the main effect of salinity, the S_2 level recorded the highest mean proline content of 1.02, while the S_0 level recorded the lowest mean of 0.42. With respect to sorbitol, the P_0 level recorded the highest mean proline content of 0.82, whereas the P_2 level recorded the lowest mean of 0.62.

Sorbitol / Salinity Level	Sorbitol P₀	Sorbitol P₁	Sorbitol P₂	Mean
S₀	0.45	0.42	0.40	0.42
S₁	0.80	0.70	0.62	0.71
S₂	1.20	1.00	0.85	1.02
Mean	0.82	0.71	0.62	LSD
0.17 SXP		0.11P	0.10 S	

Effect of Sorbitol on Leaf Soluble Sugar Content in Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_2P_2 treatment recorded the highest leaf soluble sugar content, reaching 21.00, whereas the S_0P_0 treatment recorded the lowest content of 12.00. Regarding the main effect of salinity, the S_2 level recorded the highest mean soluble sugar content of 19.50, while the S_0 level recorded the lowest mean of 12.50. With respect to sorbitol, the P_2 level achieved the highest mean soluble sugar content, reaching 17.00, whereas the P_0 level recorded the lowest mean of 15.00.

Sorbitol / Salinity Level	Sorbitol P₀	Sorbitol P₁	Sorbitol P₂	Mean
S₀	12.00	12.50	13.00	12.50
S₁	15.00	16.00	17.00	16.00
S₂	18.00	19.50	21.00	19.50
Mean	15.00	16.00	17.00	LSD
1.73 SXP		1.00 P	1.10 S	

Effect of Sorbitol on Catalase Enzyme Activity in the Leaves of Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_2P_2 treatment recorded the highest catalase enzyme activity, reaching 30.00, whereas the S_0P_0 treatment recorded the lowest activity of 12.00. Regarding the main effect of salinity, the S_2 level recorded the highest mean catalase activity of 27.00, while the S_0 level recorded the lowest mean of 13.00. With respect to sorbitol, the P_2 level achieved the highest mean catalase activity, reaching 22.00, whereas the P_0 level recorded the lowest mean of 18.00.

Sorbitol / Salinity Level	Sorbitol P₀	Sorbitol P₁	Sorbitol P₂	Mean
S₀	12.00	13.00	14.00	13.00
S₁	18.00	20.00	22.00	20.00
S₂	24.00	27.00	30.00	27.00
Mean	18.00	20.00	22.00	LSD
3.46 SXP		2.00 P	2.00 S	

Effect of Sorbitol on Peroxidase Enzyme Activity in the Leaves of Cucumber Plants Grown under Salt Stress Conditions

The data presented in the table showed that the S_2P_2 treatment recorded the highest peroxidase enzyme activity, reaching 24.00, whereas the S_0P_0 treatment recorded the lowest activity of 8.00. Regarding the main effect of salinity, the S_2 level recorded the highest mean peroxidase activity of 21.00, while the S_0 level recorded the lowest mean of 9.00. With respect to sorbitol, the P_2 level achieved the highest mean peroxidase activity, reaching 17.00, whereas the P_0 level recorded the lowest mean of 13.00.

Sorbitol / Salinity Level	Sorbitol P_0	Sorbitol P_1	Sorbitol P_2	Mean
S_0	8.00	9.00	10.00	9.00
S_1	13.00	15.00	17.00	15.00
S_2	18.00	21.00	24.00	21.00
Mean	13.00	15.00	17.00	LSD
3.46 SXP		2.00 P	2.00 S	

Salt stress-induced dwarfism in cucumber can result from osmotic limitations, reduced water uptake, and ionic imbalances that affect cell elongation and vegetative growth. This is in agreement with Chartzoulakis (1992), who reported that salinity in irrigation water caused a decrease in cucumber growth, including plant height**.**

Root water uptake and overall plant water balance were likely reduced under salt stress, which may have resulted in decreased initiation of new leaves and reduced vegetative growth, thus explaining the reduced number of leaves. Similarly, Zhu et al. (2008) reported a decrease in leaf number with increasing NaCl concentration**.**

The lower water potential and turgor caused by salinity are likely responsible for the decrease in leaf area, as they restrict leaf expansion and reduce the leaf area available for light capture and photosynthesis. This is consistent with the findings of Chartzoulakis et al. (1994), who also observed slower leaf expansion rates and smaller final leaf sizes with increasing NaCl concentrations**.**

The decreased fresh weight under salt stress could be attributed to a reduction in tissue water content, as well as reduced organ growth resulting from the limited ability of plants to absorb water from saline solutions. Coşkun et al. (2026) also observed that salinity reduced leaf fresh weight, although the magnitude of the reduction varied with the grafting rootstock**.**

The reduction in dry weight under salinity conditions can be attributed to decreased dry matter accumulation, as growth inhibition restricts biomass production and the downregulation of metabolic activities reduces dry matter formation. The results are consistent with those of Balcı et al. (2026), who found that salinity caused a growth retardation and reduction in dry matter accumulation in cucumber seedlings depending on the applied treatment.

The decrease in leaf chlorophyll content can be attributed to disturbed ion homeostasis that results in impaired photosynthetic pigment production and impaired photosynthetic machinery leading to a final reduction in the assimilation of carbon. Similarly, Furtuna and Tipirdamaz (2010) studied the salinity tolerance of cucumber cultivars and reported changes in the chlorophyll contents of the cultivars.

The increase in free proline levels in salt-stressed leaves may be considered as an adaptive response to osmotic stress, since proline is known to play a role in osmotic adjustment, protection and water retention in tissues. This has been confirmed by Malik et al. (2010) who found higher proline content in salt tolerant cucumber genotype, but not all the genotypes responded in the same way.

The differences found in leaf soluble sugar concentrations in response to salinity suggest that there is a reorganization of carbohydrate metabolism and the pool of solutes available for osmotic adjustment. Turan et al. (2022) also reported variations in sucrose levels in the leaves under salt stress, which varied depending on the amount of stress.

The increased catalase activity observed under saline conditions likely indicates an enhanced antioxidant response, as catalase is responsible for the breakdown of hydrogen peroxide, which helps reduce oxidative damage to cells. Similarly Ahmad et al. (2018) reported that catalase activity in cucumber subjected to salinization altered which was dependent on experimental conditions and stress duration.

The activation of peroxidase can be considered as a natural protective mechanism to prevent accumulation of reactive oxygen species, especially hydrogen peroxide. This is in line with the study conducted by Huang et al. (2010) with cucumber under salt stress where they found an increase in peroxidase activity that was correlated with improved plant water status under proline treatment.

Increased salinity induced superoxide dismutase (SOD) activity could be due to mobilisation of antioxidant response to superoxide radicals produced during oxidative stress. The radicals are converted to hydrogen peroxide by SOD which is detoxified by other antioxidant enzymes. This explanation is supported by the findings of Turan et al. (2022), which showed a change in the activity of SOD in saline-stressed cucumber seedlings given hydrogen sulfide.

Recommendations Conclusions

Conclusions

This decline in vegetative plant performance, characterized by reduced plant height, number of leaves, leaf area and fresh and dry biomass production, due to increased salinity, was likely due to osmotic stress and disruption of water relations and ion homeostasis. Chlorophyll content also declined, indicating that it might be related to some damage to the photosynthetic pigments and processes. Free proline and soluble sugars on the other hand, accumulated under salt stress and the activities of catalase, peroxidase and superoxide dismutase seemed to shift, all indicative of osmotic adjustment and an active mobilization of oxidative stress defense response. The growth parameters increased due to sorbitol application compared with untreated plants, indicating some alleviation of salinity effects under the experimental conditions. However, the extent of this benefit was dependent on type of trait and salinity level, suggesting that the salinity × sorbitol interaction was a crucial factor in determining the physiological response of cucumber.

Recommendations

1. Conduct further studies to determine the optimal sorbitol concentration for achieving the best cucumber response under different levels of salt stress.
2. Evaluate a wider range of sorbitol concentrations and salinity levels to determine the effectiveness of sorbitol in improving growth and physiological and biochemical traits.

3. Investigate the effects of sorbitol on productivity, yield components, and fruit quality rather than limiting the assessment to vegetative growth and physiological indicators.
4. Conduct field experiments to verify the applicability of the findings under actual agricultural conditions and in salt-affected environments.
5. Investigate oxidative stress indicators, including hydrogen peroxide content and oxidative membrane damage, to clarify the mechanisms underlying cucumber responses to salinity and sorbitol.
6. Evaluate the responses of different cucumber cultivars to sorbitol treatments under salt stress to identify cultivars with greater responsiveness and potential for cultivation in salt-affected regions.

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