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Alleviation of soil and irrigation water salinity stress in early sweet grape (*Vitis vinifera* L.) seedlings through the application of selective inducers

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Abstract

This study investigated the effects of various anti-salinity compounds on Early Sweet grape seedlings grown under salinity conditions during the 2021 and 2022 seasons. Seedlings were cultivated in soil with 2000 ppm salinity and irrigated with saline water at 1700 ppm. Six compounds (arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate) were applied at 100 ppm concentration through foliar sprays at monthly intervals from March to August. Results demonstrated that all tested compounds significantly improved growth parameters, root characteristics, and nutrient uptake (N, P, K, and Ca) while reducing Na and Cl uptake compared to untreated seedlings under salinity stress. The effectiveness of the compounds in mitigating salinity stress, in descending order, was chitosan > salicylic acid > potassium silicate > mannitol > arginine > citric acid. These findings suggest that foliar application of anti-salinity compounds, particularly chitosan and salicylic acid at 100 ppm, can effectively alleviate the adverse effects of salinity on Early Sweet grape seedlings. The study recommends six monthly applications of these compounds from March to August to enhance the growth and development of grape seedlings under saline conditions.

Keywords: Salinity, salicylic acid, chitosan, grapevine seedlings, nutrient uptake, abiotic stress.

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1. Introduction

Grapes are considered one of the most popular and favorite fruit crops in the world. In Egypt, it is ranked the third fruit crop after citrus and mangoes. Due to its high net income, the cultivated area has rapidly increased, particularly in the reclaimed lands (Ahmed, 2019). Most of the new lands of Egypt are sandy and/or calcareous soils. The vineyards extension in the newly reclaimed land faces many problems, including soil salinity. Because of the elevated water table, particularly when combined with inadequate drainage, progressive salt deposition poses a significant issue in many of Egypt's cultivated areas. In addition, the use of soluble fertilizers also causes soil solution salinity (Shin *et al*., 2022). Grapevine is considered moderately tolerant to salinity, and the damage is primarily caused by chloride ions. Symptoms of salinity start with leaf burns, shoot die back, leaf fall, and finally death of the vine (Mohammadkhani *et al*., 2013). Rootstock, scion, irrigation method, soil type and climate or combinations of these elements determine grapevine response to salinity. Furthermore, if some of the factors are changed while keeping the same irrigation water, totally different results can be achieved (Corso and Bonghi, 2014; Procházková *et al*., 2016). The subtle impacts of salinity lead to decreasing growth, related to somatic effects, decreasing water absorption, nutritional imbalances, and the specific harmful effects of ions such as sodium and chlorine on fruit trees (Shahid *et al*., 2020; Syvertsen and Garcia-Sanchez, 2014). Salinity, a significant stress for plant development, is increasingly becoming a critical issue due to global desertification. Increasing salinity levels causes a reduction in transpiration and biomass in grapevines, and a direct linear relationship exists between the transpiration amount and the weight of produced biomass (Singh, 2022; Zhou-Tsang *et al*., 2021). Salinity caused by soil and irrigation water is a serious problem. The effect is an obvious depression on growth, tree nutritional status, and fruiting of different fruit crops (Ali *et al*., 2013; El-Hanafy, 2017). Each year more lands become non-productive due to salinity (Kumar and Sharma, 2020). It is necessary to alleviate the negative effects of abiotic stresses on plants, especially soil and irrigation water salinity, by improving the fertility of arid lands and improving tree fruiting via modern technologies (Rahim *et al*., 2024). One effective way to solve the problem of salinity stress is to use substances such as amino acids, potassium silicate, humic acid, chitosan, citric acid, mannitol and salicylic acid etc. (Abou-Sreea *et al*., 2022; Ahmad *et al*., 2022; Costa *et al*., 2018; Lasheen *et al*., 2024). Previous studies showed that the use of salicylic acid, citric acid, chitosan, amino acids, mannitol, and potassium silicate were effective substances for reducing soil and water salinity stress (Amiri *et al*., 2014a; Hadwiger, 2013; Kaya *et al*., 2013; El-Hanafy, 2017; Mohamed-Attiat, 2016; Rizk, 2017). They found from their studies that these compounds have a positive effect on alleviating the adverse effects of soil and water salinity on the growth and fruiting of fruit crops. Therefore, the target of this work was to elucidate the effects of some compounds on enhancing the tolerance of Early Sweet grapevines to soil and irrigation water salinity.

2. Materials and methods

2.1 Irrigation water applied

The current experiment was conducted during two succeeding seasons of 2021 and 2022, at the nursery of Mallawy Agricultural Experimental Station located in Minia governorate, Egypt. The objective was to assess the response and tolerance of the seedlings of Early Sweet grapevine seedlings to soil and irrigation with saline water. In early February of both seasons, 105 one year old healthy and own-rooted seedlings of Early Sweet grapevines having nearly similar vigor were selected for the experiment. All seedlings were planted in black polyethylene pots of 30 cm diameter and 50 cm depth having three holes/pot for better drainage. Each pot was filled with 6 kg of saline soil. The soil was prepared from sodium chloride and sodium sulfate at a percentage of 1:1 by weight. The soil underwent washings with water, was air-dried, and was analyzed for mechanical physical qualities, water retention capacities, and chemical analysis in accordance with the methods of Margesin *et al*. (2005). The data recorded from the soil analysis are given in Table (1).

Table (1): Analysis of the tested soil.

Parameter	Values	Parameter	Values
Particle size distribution	-	Organic matter (%)	0.7
Sand (%)	88.0	Total N%	0.04
Silt (%)	11.5	Available P (olsen ppm)	21.0
Clay (%)	0.5	Available K (ammonium ppm)	160.0
Texture	Sandy	Water holding properties	-
pH (1:2.5 texture)	7.3	Field capacity (%)	7.0
Total $CaCO_3$ (%)	0.32	Witting point (%)	2.2
EC (1:2.5 extracted) ds/m^{-1}	0.01	Available water (%)	4.5

The experimental treatments involved foliar application of various inducers at a concentration of 100 ppm, along with a control group consisting of saline soil without any inducer application. The inducers tested were arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate. Each inducer was applied at the same concentration of 100 ppm, allowing for a standardized comparison of their effects. The control group served as a baseline to evaluate the impact of these inducers on plant growth and development under saline soil conditions. All treatments were replicated three times, with five seedlings per treatment. The soil was salted to 2000 ppm by adding salt (sodium chloride and sodium sulphate at 1:1 by weight) per kg of soil. The seedlings were irrigated with saline water at 1700 ppm concentration till field capacity. The inducers were sprayed six times each in the first week of March, April, May, June, July, and August in both seasons. Triton B was added to all materials solutions at 0.05% as a wetting agent. Salicylic acid was dissolved in a few drops of Ethyl alcohol. Chitosan was prepared by using 0.6% acetic acid and adding 25% glycerol as plasticizer, and the pH of the water was adjusted to 5.6 using 1.0 N sodium hydroxide (Abd-Alla and Wafaa, 2010). Spraying was done till runoff (0.25 liter/transplant). Inorganic nitrogen, phosphorus, and potassium fertilizers were administered to grapevine transplants in all treatments at the usual recommended rate for seedlings of this age (one year old) to ensure that these nutrients did not hinder development. The nitrogen was administered at a rate of 5.0 g ammonium nitrate (33.5% N) in each pot, split into three equal doses. As a source of P, 0.05% orthophosphoric acid was sprayed three times, while K was provided in three equal doses of 5.0 g potassium sulfate (48.0% K_2O) in each pot. These fertilizers were administered once every two months, beginning in mid-March in both seasons. After one month, a solution of 0.05% ferrous sulfate and 0.02% zinc sulfate and micronutrients were applied. Also, after two months of the plantation, a solution containing 0.05% manganese sulfate, 0.02% copper sulfate, and 0.02% boric acid was sprayed three times at two-month intervals. The experiment was designed as a Completely Randomized Design (CRD) with seven treatments. Each treatment was replicated three times, with five transplants per treatment. The data were analyzed using SAS statistical software (version 9.4, SAS Institute, Cary, NC, USA). Data regarding various parameters were collected at the end of each growing season (last week of September). The parameters measured included survival percentage; growth characters such as plant height (cm), number of lateral shoots per plant, leaf area (cm^2), total leaf area per plant, and dry weight of the whole plant (g); total chlorophyll content of leaves using a chlorophyll meter (Minolta SPAD 502 plus), with ten leaves from the fourth basal expanded leaf of the shoot collected for this purpose; leaf proline content calculated on a dry weight basis (Ls, 1973); root characters including main root length (cm), dry weight of roots per plant (g), and number of secondary roots per plant; and uptake of N, P, K, Ca, Na, and Cl (mg/plant) were estimated in Department of Soils and Water Sciences, Faculty of Agriculture, Al-Azhar University (Assiut Branch), Assiut, Egypt according to (Wild *et al*., 1979). Statistical analysis was performed on all collected data using the Least Significant Difference (L.S.D.) test at 5% level of the probability of comparing means of all treatments.

3. Results

The effects of arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate on different plant parameters are as follows:

3.1 Survival percentage

The data in Table (2) shows that treating Early Sweet grape seedlings grown under saline conditions (salinity of soil and irrigation water were 2000 and 1700 ppm, respectively) six times with arginine, mannitol, citric acid, salicylic acid, chitosan and potassium silicate each at 100 ppm significantly enhanced survival percentage compared to untreated seedlings (control). The best results were shown by chitosan, salicylic acid, potassium silicate, mannitol, arginine, and citric acid in descending order. Early Sweet grape seedlings grown under saline conditions when subjected to six times spraying with chitosan at 100 ppm gave the maximum percentage of survival (81.5 and 83.6%) in both seasons. This was followed by applying salicylic acid (77.4 and 78.0%) while the lowest survival percentage (65.4 and 66.0%) was recorded in untreated (control) seedlings. The increment percentage of survival attained 24.62, 26.67, 18.35 and 18.18% due to spraying chitosan and salicylic acid compared to check treatments during the two studied seasons, respectively. These results indicated that spraying chitosan is an effective tool to reduce the negative effects of soil and irrigation water salinity on plants.

3.2 Vegetative growth characteristics

The data in Tables (2 and 3) showed that treating Early Sweet grape seedlings grown under saline conditions six times with arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate each at 100 ppm significantly increased plant height, number of lateral shoots/plant, leaf area and total leaf area as well as dry weight of whole plant, main root length, number of secondary roots/plant and dry weight of roots per plant compared to control treatment.

Table (2): Effect of spraying arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate on the survival percentage plant height and leaf traits of Early Sweet grape seedlings during 2021 and 2022 seasons.

Treatments	Survival (%)		Plant height (cm)		No. of lateral/shoots /plant		Leaf area $(cm)^2$		Total leaf area/plant (m^2)	
	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022
T_1: Control	65.4 f	66.0 f	72.4 g	72.6 g	6.5 g	7.2 f	81.0 g	82.0 f	0.31 g	0.31 d
T_2: Arginine	69.0 e	69.7 e	78.5 e	79.0 e	9.8 e	10.5 d	88.5 e	90.0 d	0.39 e	0.41 c
T_3: Mannitol	71.3 d	72.0 d	81.5 d	83.0 d	10.6 d	11.0 d	90.0 d	91.0 d	0.43 d	0.44 c
T_4: Citric acid	68.2 e	69.0 e	74.8 f	75.0 f	8.2 f	9.0 e	84.5 f	86.0 e	0.35 f	0.36 d
T_5: Salicylic acid	77.4 b	78.0 b	89.5 b	91.0 b	12.2 b	13.5 b	94.5 b	95.0 b	0.51 b	0.52 a
T_6: Chitosan	81.5 a	83.6 a	94.0 a	95.0 a	14.0 a	14.8 a	96.0 a	97.0 a	0.53 a	0.55 a
T_7: Potassium silicate	74.2 c	75.0 c	86.7 c	88.0 c	11.4 c	12.0 c	92.0 c	93.0 c	0.47 c	0.48 b
L.S.D. at 5%	1.6	1.7	1.8	1.9	0.6	0.7	1.2	1.3	0.02	0.04

Significant differences in these growth aspects were observed between the six materials used. Promoting these growth aspects was significantly associated with using the inducers, *i.e.* citric acid, arginine, mannitol, potassium silicate, salicylic acid, and chitosan in ascending order. Subjecting the seedlings to soil and irrigation water salinity in 2000 and 1700 ppm, respectively, without any treatment gave the lowest values. The maximum values of all these growth parameters were recorded in the seedlings treated with chitosan during both seasons. These results were similar through both seasons. The highest total leaf area/plant (0.53 and 0.55 cm^2), whole plant dry weight (34.0 and 35.6 g), and root dry weight/plant (4.10 and 4.25 g) were recorded in plants sprayed with chitosan followed by salicylic acid (0.51 and 0.52 m^2), (33.5 and 34.0 g) and (3.92 and 4.00 g) during the two studied seasons, respectively. On the other hand, the least values of these traits (0.31 and 0.31 cm^2), (20.5 and 21.0 g), and (3.18 and 5.22 g) were recorded in check plants. Hence, the increment percentage of total leaf area/plant attained 70.97, 77.42, 65.52 and 67.74%, whole plant dry weight (65.85 and 69.52%) and (63.41 and 61.90%), and root dry weight (28.93 and 31.99%) and (23.27 and 24.22%) due to spraying chitosan and salicylic acid compared to unsprayed ones during the two studied seasons, respectively. In general view, it could be concluded that spraying with chitosan is considered an appropriate means of tolerance to salinity and drought stress.

Table (3): Effect of spraying arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate on dry weight of whole plant and roots/plant, main root length, and number of secondary roots per plant of Early Sweet grape seedling during 2021 and 2022 seasons.

Treatments	Dry weight of whole plant (g)		Dry weight of roots/ plant		Main root length (cm)		Number of secondary roots/plant	
	2021	2022	2021	2022	2021	2022	2021	2022
T_1: Control	20.5 f	21.0 e	3.18 f	3.22 f	33.0 g	33.8 f	38.0 g	39.0 g
T_2: Arginine	29.0 d	29.5 d	3.41 e	3.45 e	37.5 e	38.4 d	44.0 e	44.2 e
T_3: Mannitol	30.8 c	31.4 c	3.55 d	3.62 d	41.0 d	41.6 c	44.9 d	45.5 d
T_4: Citric acid	27.0 e	28.5 d	3.25 f	3.30 f	35.2 f	36.0 e	41.5 f	42.0 f
T_5: Salicylic acid	33.5 ab	34.0 b	3.92 b	4.00 b	44.0 b	44.4 b	47.8 b	48.5 b
T_6: Chitosan	34.0 a	35.6 a	4.10 a	4.25 a	45.2 a	46.5 a	48.8 a	49.5 a
T_7: Potassium silicate	32.5 b	33.2 b	3.76 c	3.81 c	42.5 c	43.6 b	46.5 c	47.0 c
L.S.D. at 5%	1.3	1.4	0.08	0.09	1.2	1.3	0.8	0.9

3.3 Leaf chlorophyll, proline, and uptake of N, P, K, Ca, Na, and Cl

Data in Tables (4 and 5) demonstrate that spraying the seedlings with arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate significantly increased leaf total chlorophyll and proline contents as well as uptake of N, P, K, and Ca in the plant as compared to the control. Conversely, the uptake of Na and Cl significantly decreased due to spraying these materials compared to unsprayed ones. There was a considerable increase with using chitosan, salicylic acid, potassium silicate, mannitol, arginine, and citric acid respectively. Various anti-salinity compounds had significant differences in these aspects. The highest all-plant chlorophyll, proline content, and uptake of N, P, K, and Ca and the minimum uptake of Na and Cl were recorded in seedlings grown under salinity and application of chitosan (100 ppm) in both seasons. Parallel results were recorded during both seasons.

Table (4): Effect of spraying arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate on total chlorophylls, proline, and N and P uptake of Early Sweet grape seedlings during 2021 and 2022 seasons.

Treatments	Total chlorophylls (SAPD)		Proline (mg/100g)		N uptake (mg/ plant)		P uptake (mg/plant)	
	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022
T_1: Control	50.11 c	51.86 d	32.62 d	34.18 c	325 c	333 d	44.5 d	46.2 d
T_2: Arginine	58.29 b	61.30 bc	36.92 bc	37.89 bc	358 bc	362 c	51.5 c	52.6 c
T_3: Mannitol	61.39 b	64.52 b	38.11 b	38.91 b	377 b	380 bc	53.8 bc	55.4 bc
T_4: Citric acid	56.33 b	58.11 c	35.81 c	36.24 c	341 c	355 cd	48.2 c	49.5 cd
T_5: Salicylic acid	66.48 ab	69.11 ab	40.32 ab	41.75 a	395 ab	405 ab	58.8 ab	60.0 ab
T_6: Chitosan	68.74 a	72.15 a	41.68 a	41.87 a	410 a	422 a	61.0 a	63.5 a
T_7: Potassium silicate	63.73 ab	66.33 ab	39.85 b	40.49 ab	390 ab	392 b	56.9 b	57.2 b
L.S.D. at 5%	5.56	6.11	1.83	2.18	21.2	22.8	3.6	3.9

The highest values of total chlorophyll (68.74 and 72.15 SPAD) and proline (41.68 and 41.87 mg/100g) and least values of Na uptake (74.0 and 72.0 mg/plant) and Cl uptake (34.2 and 33.5 mg/plant) were recorded in plants that were treated with 100 ppm chitosan during the two studied seasons, respectively. On the other side, the least values of total chlorophyll (50.11 and 51.86 SPAD) and proline content (32.62 and 34.18 mg/100g) and highest values of Na uptake (91.0 and 90.5 mg/plant) and Cl uptake (48.04 and 46.5 mg/plant) were found in untreated seedlings during the two studied seasons, respectively. Hence, the increment percentage of total chlorophyll (37.18 and 39.12%) and proline (27.77 and 22.50%), as well as the decrement percentage of Na uptake (18.68 and 20.44%) and Cl uptake (28.75 and 27.96%) was due to spraying chitosan compared unsprayed ones during the two studied seasons, respectively.

Table (5): Effect of spraying arginine, mannitol, citric acid, salicylic acid, chitosan, and potassium silicate on K, Ca, Na, and Cl uptake of Early Sweet grape seedlings during 2021 and 2022 seasons.

Treatments	K uptake (mg/plant)		Ca uptake (mg/plant)		Na uptake (mg/plant)		Cl uptake (mg/plant)	
	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022	Season 2021	Season 2022
T_1: Control	208.0 c	212.5 c	410.0 g	415.0 g	91.0 a	90.5 a	48.0 a	46.5 a
T_2: Arginine	222.0 bc	225.0 bc	425.0 e	430.0 e	86.5 b	86.2 b	43.5 c	42.0 b
T_3: Mannitol	230.0 b	233.0 b	430.0 d	433.0 d	84.5 c	83.2 c	40.8 d	39.6 c
T_4: Citric acid	215.0 c	219.2 c	418.0 f	420.0 f	88.0 b	87.8 b	46.2 b	45.5 a
T_5: Salicylic acid	244.0 a	251.0 a	446.0 b	450.0 b	77.0 e	75.4 e	36.0 f	35.0 e
T_6: Chitosan	252.0 a	254.0 a	450.0 a	455.0 a	74.0 f	72.0 f	34.2 g	33.5 f
T_7: Potassium silicate	241.5 ab	244.8 ab	437.0 c	440.0 c	81.2 d	80.0 d	38.8 e	37.5 d
L.S.D. at 5%	11.9	12.2	2.3	2.5	1.6	1.8	1.2	1.3

4. Discussion

Salinity and drought are major abiotic factors that limit agricultural production worldwide (Minhas *et al*., 2017; Nawaz *et al*., 2020). The damaging impact of salinity on grape production will worsen because of the hostile impacts of climate change on the existing water resources and their quality (Mirás-Avalos and Intrigliolo, 2017). The detrimental impact of salt on the growth of Early Sweet grapevines may be associated with its adverse effects on cell division, plant metabolism, cytoplasm, plant pigments photosynthesis, respiration, and uptake of some nutrients and water (Ahmad *et al*., 2023; Shahid *et al*., 2020). The limiting effect of chitosan on the negative impacts of salinity on seedling development can be associated with its role in inhibiting reactive oxygen species and safeguarding plant cells from damage, as well as its influence on enhancing lignification of plant cells, which in turn leads to a reduced transpiration rate (Hadwiger, 2013). Chitosan has positive effects on increasing growth and development due to increased enzymatic activation of nitrogen metabolism and transportation to functional leaves, leading to improved vegetative growth development, which improves tree nutritional status (Górnik *et al*., 2008; Malerba and Cerana, 2016; Shen *et al*., 2024). Applying antioxidants increases the biosynthesis of alpha-keto glutaric acid, which is united with ammonia for the formation of amino acids and proteins that enhance cell division and the building of most organic foods (Abou-Zaid and Eissa, 2019; Salm *et al*., 2021). The beneficial effects of salicylic acid and citric acid on counteracting the adverse effects of salinity on the growth and nutritional status of grapevines might be attributed to their positive action on enhancing cell division and the biosynthesis of organic foods. It also increases plant pigments and reduces Reactive Oxygen Species (ROS) and oxidative stress while also improving the tolerance of the transplants to abiotic and biotic stresses (Ekbiç and Yorulmaz, 2023; Joseph *et al*., 2010). Also, the positive effects of mannitol on hindering the harmful effect of salinity on the growth of Early Sweet grape seedlings are mainly attributed to its effect on improving the osmotic pressure of plant tissues and proline biosynthesis. The metabolism of mannitol may influence plant reactions to biotic and abiotic stresses. It increases the tolerance to salt and osmotic stress because of its role as a compatible solute (Kaya *et al*., 2013; Singh *et al*., 2015). The positive effects of potassium silicate on impeding Reactive Oxygen Species (ROS), enhancing abiotic and biotic stress tolerance, and promoting the biosynthesis of organic compounds explain the present results of potassium silicate in lessening the harmful effects of salinity on the growth of Early Sweet transplants. Silicon enhances drought and salinity tolerance in plants by regulating water balance, sustaining photosynthetic activity, and preserving leaf erectness and xylem vessel structure during elevated transpiration rates (Khan *et al*., 2019). The positive effects of amino acids on increasing cell division, formation of natural hormones and plant pigments, as well as retarding Reactive Oxygen Species (ROS) could explain the present results (Shahrajabian *et al*., 2022). The current study clearly shows that survival percentage, total leaf area per plant, total chlorophyll, and proline increased by about 25.6, 74.1, 38.1, and 25.1%, respectively, due to spraying the seedlings with chitosan, while these increases were about 18.3, 66.10, 27.5, and 20.3% due to spraying with potassium silicate compared to unsprayed ones, respectively. On the other hand, the corresponding decrement percentage of Na and Cl uptake attained 18.6, 28.4 and 11.2%, respectively. These findings illustrate the importance of spraying chitosan or potassium silicate to overcome the damage caused by salinity of soil and irrigation water. The results mentioned above concerning the effects of chitosan are in accordance with those obtained by (El-Eleryan, 2015). The results regarding the other compounds, *i.e*., salicylic acid, citric acid, and mannitol, are also in harmony with previous studies (Amiri *et al*., 2014b; El-Sayed-Eman, 2017; Gill and Tuteja, 2010; Kaya *et al*., 2013; Mohamed-Attiat, 2016; Salama and EMA, 2019). Other researchers also obtained similar results while using potassium silicate and amino acids for better growth in olives and date palms (Rizk, 2017). Similarly, the findings support the beneficial effects of amino acids on the growth of Early Sweet grapevine seedlings (El-Hanafy, 2017; Khattab *et al*., 2012).

5. Conclusion

This study highlights the efficacy of foliar-applied anti-salinity compounds in mitigating salt stress in Early Sweet grape seedlings. Among the tested treatments, chitosan and salicylic acid at 100 ppm demonstrated the highest effectiveness in improving growth parameters, root characteristics, and nutrient balance while reducing Na and Cl uptake. Regular application from March to August significantly enhanced seedling resilience to salinity. These findings support the use of natural anti-salinity treatments, especially Chitosan and Salicylic acid as a sustainable strategy for improving grapevine growth under saline conditions.

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