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Alleviating Salinity Stress in Maize Growth, Nutrient Content and Yield through Foliar Application of Ascorbic Acid, Tocopherol and Arginine

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ABSTRACT

Soil salinity has emerged as a worldwide menace to the sustainability of agricultural systems, mainly affecting the quality and productivity of maize. This study examined the impact of ascorbic acid, tocopherol, and arginine (1 g/L) applied as a foliar spray alone and in combination on mitigating salinity stress effects on maize growth, yield, and nutrient content. The experiment was carried out during the 2023 and 2024 growing seasons in South Port Said, Port Said Governorate, Egypt, using a completely randomized design. The results indicated that all treatments enhanced vegetative growth attributes (plant height, leaf area index, crop growth rate, and plant dry weight), yield components (number of grains per ear, 100-grain weight, average grain weight, stover yield, grain yield, and total biological yield), as well as grain nutrient content (N, P, and K). The combined use proved to be the most impactful as it enhanced grain yield by 150.4% and stover yield by 149.7% on average for both seasons. Furthermore, the use of these eco-friendly biostimulants demonstrates strong potential for mitigating the adverse effects of salinity stress in maize production systems.

Keywords: biological yield, crop growth rate, grain yield, leaf area index, nutrients content, stover yield.

INTRODUCTION

Maize (*Zea mays* L.) is grown across a wide range of soils and climatic conditions, but its moderate tolerance to salt stress makes salt build-up in soils an important factor affecting its productivity at the global level (Farooq et al., 2015). An area covering more than 397 Mha is affected by salinity at the global level (FAO, 2005), and it is more critical in arid and semi-arid environments due to limited rainfall, high rates of evapotranspiration, and poor soil and water management, but it is worth noting that salt build-up is not limited to these environments and can occur in all climatic conditions (Farooq et al., 2015). Salinity stress (SS) affects plant growth by limiting the formation of new leaves, expansion of existing leaves, internode growth, and promotion of leaf senescence (Farooq et al., 2015). Salinity stress causes significant reductions in leaf growth rate, plant height, leaf area, and biomass production in the shoot system of the plant. Moreover, the adverse effects of SS on soil structure, nutrient availability, and plant growth cause crop yield loss (El Sabagh et al., 2021; Tarolli et al., 2024; Fatima et al., 2025). Therefore, the need to use effective techniques to mitigate the effects of SS in the soil and improve the quality of the soil cannot be overemphasized in order to increase crop yields.

The application of natural biostimulants such as ascorbic acid (AsA), tocopherol (Toc), and arginine (Arg) has been found to alleviate the adverse effects of SS. For instance, the application of AsA in barley has been found to enhance the morpho-physiological

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traits such as growth, biomass and ion balance (Hassan et al., 2021). Similarly, the application of AsA in sweet pepper has been found to effectively alleviate the adverse effects of SS by enhancing the growth parameters such as plant height, leaf number, leaf area, branching, and yield per plant (El-Beltagi et al., 2022). Recently, the application of AsA has been found to alleviate the adverse effects of SS in tomato by enhancing the growth parameters *i.e.* plant height, leaf area, dry biomass, and yield (El-Beltagi et al., 2026). Similarly, applying AsA to maize has been demonstrated to alleviate the harmful impacts of SS by enhancing the growth parameters such as vegetative growth and nutritional composition (Fatima et al., 2025).

Furthermore, the use of Toc resulted in better ion homeostasis, which in turn resulted in better growth parameters in maize (Ali et al., 2020; Khalil et al., 2022), barley (Sadaf et al., 2025), and sunflower (Lalarukh et al., 2022) in SS conditions. It was also found in pot experiment studies that foliar application of 25 and 50 ppm of alpha tocopherol resulted in better growth parameters in maize, along with increased uptake of K^+, thereby improving productivity in maize (Dekhil, 2021).

Similarly, the applied use of Arg has been reported to mitigate the adverse effects of SS on growth, yield, and productivity of maize plants. It improves the uptake of K^+ and reduces Na^+ toxicity, thus maintaining ion homeostasis and improving plant water relations (Saravanan et al., 2026). In canola plants, the foliar application of arginine has been reported to significantly stimulate growth, improve K^+ content, and enhance yield parameters under SS. Similarly, in pea plants, arginine application has been reported to show significant effects on growth and yield parameters covering plant height, leaf area, dry biomass, number of pods per plant, green pod weight per plant, and seed dry weight under SS (El-Beltagi et al., 2024).

Most investigations concentrated on analyzing the single effects of ascorbic acid, tocopherol, and arginine on various crops, focusing on their potential to enhance plant growth and productivity under SS conditions. However, little information has been documented on the application of the three compounds in combination. Therefore, the main objective of this study was to evaluate the effectiveness of the integrated application of ascorbic acid, tocopherol, and arginine compared to their individual application in improving the growth traits and yield of maize under SS conditions. The integrated application of the compounds in this study was believed to improve the growth traits and yield of maize.

MATERIAL AND METHODS

Location of the experiment and soil analysis

The research was conducted in South Port Said, Egypt (31°08’20” N, 32°17’29” E) over two consecutive summer seasons, 2023 and 2024. During this time, the average temperature ranged from 26°C to 27°C, and relative humidity ranged from 65% to 70%. This region receives high solar radiation, averaging 11 to 12 hours/day, equivalent to about 23 to 26 MJ/m²/day. A yellow maize hybrid (Single Hybrid SC 168) was employed. This was obtained from the Cereal Crops Department, Field Crops Institute, Agricultural Research Center, Giza, Egypt. Alfalfa (*Trifolium alexandrinum* L.) was the preceding crop. Before the experiment, surface soil samples were taken at 0-20 cm intervals; their chemical properties were analyzed using the methods described by Dane and Topp (2020) and Sparks et al. (2020), with the results shown in Table 1.

Table 1. Mean values of selected chemical soil properties at the experimental location prior to planting during 2023 and 2024 season

Seasons	EC	PH	Texture	Cations (ml equ/L)				Anions (ml equ/L)			
				Ca^{+2}	Mg^+	Na^+	K^+	CO_3^-	HCO_3^-	Cl^-	SO_4^-
2023	7.6	8.68	clayey	9.88	11.64	63.1	2.29	-	1.1	64.9	21.09
2024	7.2	8.94	clayey	10.12	12.03	64.1	2.41	-	1.03	65.21	22.42

Pre-sowing soil preparation and fertilization

Soil preparation involved tilling the soil two weeks before planting and then leveling using laser technology. A completely randomized design was employed in the study, including five treatments, each replicated five times per season. Each experimental unit consisted of five ridges, each 3 m in length and 70 cm apart, covering an area of 10.5 m^2. The date of planting was May 25, 2023, and May 30, 2024. The plantings were done using the hill method with seeds planted 25 cm apart under high salinity conditions (Table 1). The seedlings were thinned 21 days after sowing to allow one plant per hill. Harvesting was done at the beginning of September in both seasons. Fertilizers used were 36 kg P_2O_5 ha^{-1} of calcium superphosphate fertilizer containing 15.5% P_2O_5 applied during soil preparation. Urea fertilizer containing 46% N was applied in three equal splits pre-irrigation at the rate of 288 kg N ha^{-1}. All additional management practices adhered to standard maize cultivation protocols.

Treatments

Foliar spray treatments consisted of ascorbic acid (1 g L^{-1}), tocopherol (1 g L^{-1}), and arginine (1 g L^{-1}), applied singly and in combination at 25 and 40 days after sowing. The plants were kept as controls.

Plant growth traits

At 100 days after sowing, plant height was determined by randomly selecting three uniform maize plants from each plot. Total leaf area was measured using a Laser Area Meter (CI-203). The leaf area index (LAI) was then estimated as the ratio of leaf area to ground surface area, following the formula described by Gardener et al. (1985). Crop growth rate (CGR), defined as the rate of dry matter accumulation per unit land area over time, was calculated between 80 and 100 days after sowing according to the method outlined by Radford (1967).

Nutrients content

The dried maize grains were then exposed to wet digestion with a mixture of sulfuric and perchloric acids to analyze the quantity of Nitrogen (N), Phosphorus (P), and Potassium (K) contained in the seed straw. Nitrogen content was analyzed through the Kjeldahl method, while Phosphorus and Potassium content were analyzed through spectrophotometric and flame photometer methods, respectively, as per the procedures outlined by Walinga et al. (2013).

Yield and yield components

Three random sampling points per treatment were chosen at maize maturity. From each sampling point, three plants were uprooted to assess total biomass and grain yield (Meng et al., 2022). Plants were uprooted, cleaned, and thoroughly dried to assess total biomass. For the grain yield, the maize ears in each treatment were cleaned and thoroughly dried. Five maize ears were chosen to assess the total kernel weight per ear. Ears were manually shelled, and a seed counter was used to assess 100 randomly selected seeds, measured in grams. Stover yield, consisting of leaves, stalks, and cobs left after the grain harvest, was recorded as dry matter per hectare. Biological yield was assessed by adding the dry weight of the grains and stover and was recorded in t ha^{-1}. Extent SS mitigation (%): The mean values of the evaluated traits were determined and averaged over the two growing seasons.

Statistical analysis

Analysis of variance (ANOVA) was performed on the collected data and treatment effects were considered statistically significant at $p \leq 0.05$. All statistical analyses were performed utilizing the COSTAT statistical software package (CoHort Software, 1986). When significant differences were detected, treatment means were compared utilizing Duncan's multiple range test according to Duncan (1955).

RESULTS AND DISCUSSION

Plant height, leaf area index, plant dry weight and crop growth rate

As presented in Figure 1, foliar application of ascorbic acid (AsA), tocopherol (Toc), and arginine (Arg), applied either individually or in combination, significantly improved plant height, leaf area index (LAI), plant dry weight, and crop growth rate (CGR) compared with the control in both growing seasons. The combined application of these treatments proved to be effective as it resulted in increases in plant height by 22.5% and 29.9%, followed by AsA (14.9% and 24.9%), Toc (9.8% and 7.2%), and Arg (8% and 3.8%) in 2023 and 2024, respectively. A similar trend was also followed by LAI, where the combined treatment showed a 73.6 and 123.6 percent increase over AsA (50% and 88.4%), Toc (32.1% and 40.9%), and Arg (25% and 37.3%) in the respective seasons. The plant dry weight was also maximized by the combined treatment, where the increases were (73.8% and 89.5%), followed by AsA (35% and 73.2%), Toc (21.1% and 24.1%), and Arg (11.9% and 16.1%). Similarly, CGR showed the greatest enhancement with the combined application, increasing by 111.6% and 122.7% in the two seasons, followed by AsA (56.8% and 102.6%), Toc (31.3% and 27.2%), and Arg (14.3% and 13.0%).

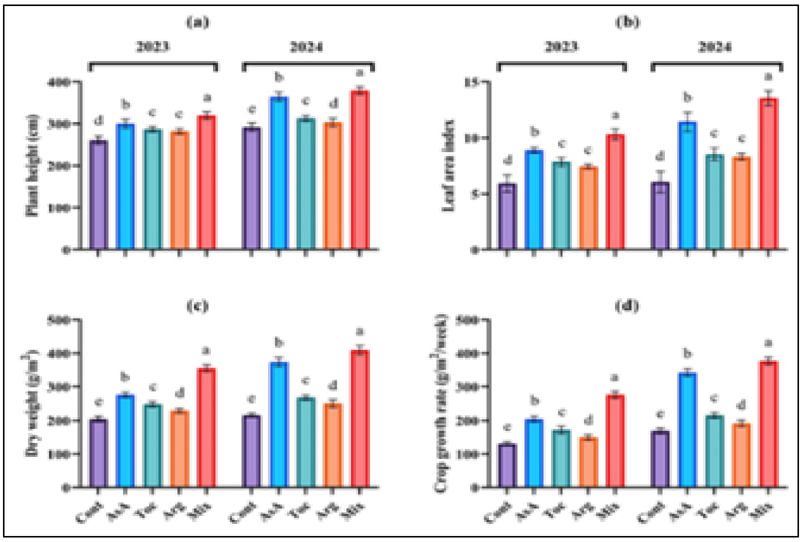

Figure 1. Influence of foliar spraying of ascorbic acid (AsA), tocopherol (Toc), and arginine (Arg) used individually or in combination (Mix) on plant height (a), LAI (b), dry weight (c) and CGR (d) in maize exposed to SS conditions during the 2023 and 2024 growing seasons. Distinct letters assigned to the bars denote significant variations among treatments at $p \leq 0.05$ based on Duncan's multiple range test.

Grain nutrients content

The data in Figure 2 clearly indicated that grain nutrient content (N, P, and K%) increased significantly due to individual and combined applications of AsA, Toc, and Arg compared to the control treatment in both seasons. The combined treatments were found to be effective compared to individual applications of AsA, Arg, and Toc. The combined use resulted in increases in N% by 132.5% and 113%, P% by 69.4% and 88.2%, and K% by 83% and 79.2% for the 2023 and 2024 seasons, respectively. Conversely, the use of AsA alone resulted in increases in N% by 93.9% and 58.8%, P% by 34% and 52.9%, and K% by 49.8% and 36.1% for the 2023 and 2024 seasons, respectively. Moreover, the use of arginine resulted in increases in nutrient content as indicated by increases in N% by 54% and 38.9%, P% by 43.1% and 44%, and K% by 45.4% and 30.1% for the two seasons. However, the use of tocopherol resulted in increases in nutrient content as indicated by increases in N% by 43.9% and 26.2%, P% by 25.7% and 31.4%, and K% by 35.1% and 28.6% in 2023 and 2024 seasons, respectively.

Number of kernels per ear, 100 grains weight and grain weight

The results obtained in Figure 3 show that the application of AsA, Toc, and Arg, both separately and in combination, has significantly increased the number of grains per ear, the weight of 100 grains, and the average weight of grains in both seasons. The use of the combination of the mentioned compounds was the most effective. The increase in the number of grains per ear was 34.2% and 58% in 2023 and 2024, respectively, followed by the application of AsA (30.4% and 13.8%), Toc (23.3% and 34.2%), and Arg (10.8% and 51.9%).

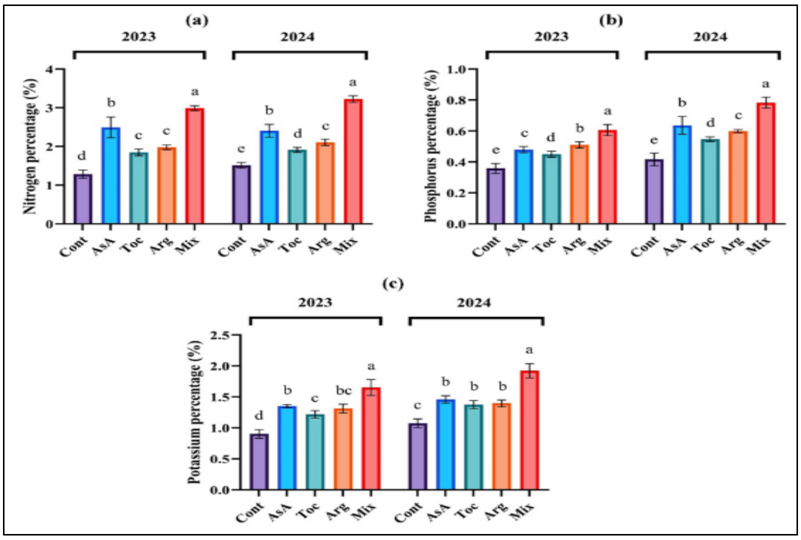

Figure 2. Influence of foliar spraying of ascorbic acid (AsA), tocopherol (Toc), and arginine (Arg) used individually or in combination (Mix) on nitrogen% (a), phosphorous% (b) and potassium% (c) in maize plants exposed to SS conditions during the 2023 and 2024 growing seasons. Distinct letters assigned to the bars denote significant variations among treatments at $p \leq 0.05$ based on Duncan's multiple range test.

Similarly, the weight of the 100 grains was found to be increased by 53% and 54.4% with the combined treatment, while the increases with the application of AsA, Toc, and Arg were found to be 42.4% and 42.2%, 24.3% and 24.8%, and 22.7% and 13.4%, respectively. In addition, the average weight of the grains was found to be significantly increased with the combined treatment, while the increases with the application of AsA, Toc, and Arg were found to be 85.5% and 61.8%, 53.2% and 67.5%, and 36% and 72.2% in 2023 and 2024 seasons, respectively.

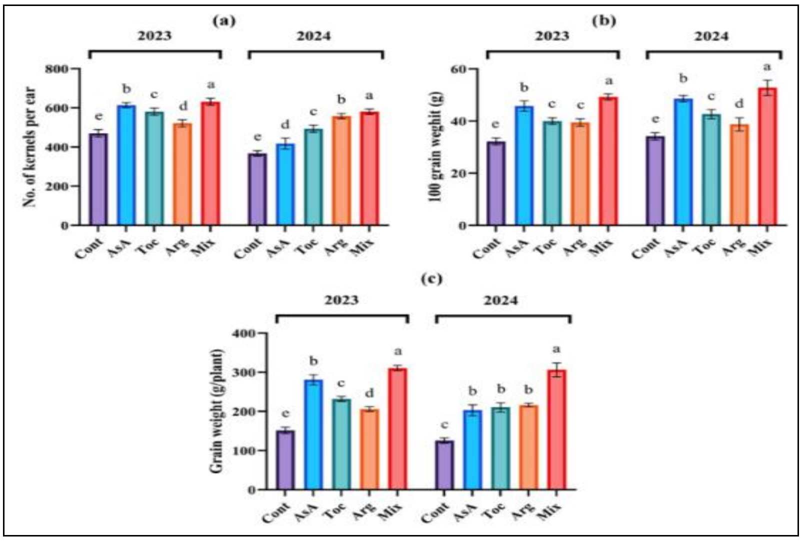

Figure 3. Influence of foliar spraying of ascorbic acid (AsA), tocopherol (Toc), and arginine (Arg) used individually or in combination (Mix) on number of kernels per ear (a), 100 grains weight (b) and grain weight (c) in maize plants exposed to SS conditions during the 2023 and 2024 growing seasons. Distinct letters assigned to the bars denote significant variations among treatments at $p \leq 0.05$ as determined by Duncan's multiple range test.

Stover yield, grain yield, and total biological yield

As presented in Figure 4, foliar application of AsA, Toc, and Arg in the foliage, both as single and combined treatments, significantly increased stover yield, grain yield, and total biological yield in both seasons. The combined treatment consistently exhibited the highest performance across all yield traits. The stover yield was increased by the combined application by 205.9% and 93.2%, followed by AsA application by 165.2% and 66.8%, Toc application by 130.5% and 35%, and Arg application by 116.5% and 20.1% in the two seasons. Likewise, the grain yield was significantly improved with increases of 181.1% and 137.7% under the combined treatment compared with the increases of 148.9% and 104.3% with AsA, 111.1% and 52.2% with Toc, and 61.5% and 36.3% with Arg in 2023 and 2024 seasons, respectively. In the similar trend, the biological yield was significantly increased with the application of the combined treatment (196.2% and 104%), followed by AsA (158.8% and 79.8%), Toc (122.8% and 42.2%), and Arg (94.9 %and 26.4%) in the first and second seasons, respectively.

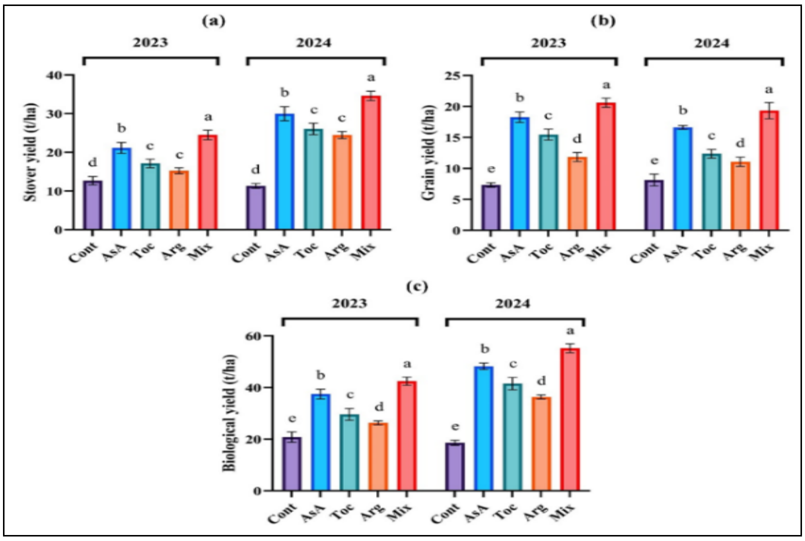

Figure 4. Influence of foliar spraying of ascorbic acid (AsA), tocopherol (Toc), and arginine (Arg) used individually or in combination (Mix) on stover yield (a), grain yield (b) and biological yield (c) in maize plants exposed to SS conditions during the 2023 and 2024 growing seasons. Distinct letters assigned to the bars denote significant variations among treatments at $p \leq 0.05$ as determined by Duncan's multiple range test.

Extent of salinity stress mitigation (%)

The data presented in Fig. 5 shows the percentage alleviation of salinity stress effects on maize growth, yield, and grain nutrient content. AsA, Toc, and Arg, applied individually and in combination, minimized the adverse effects of SS on vegetative growth traits (plant height, LAI, plant dry weight and CGR), yield components (number of grains per ear, 100-grain weight, average grain weight, stover yield, grain yield and total biological yield), and grain nutrient content (N, P, and K). It is obvious that the combined use was the most effective in mitigating SS effects, followed by AsA for vegetative growth traits and yield, while Arg was found to be more effective than AsA in improving grain nutrient content.

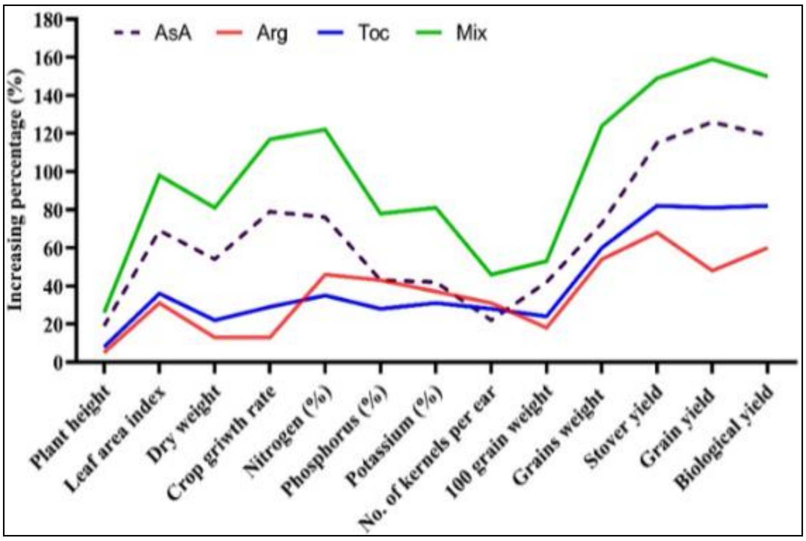

Figure 5. Percentage alleviation of SS by AsA, Toc, and Arg, applied individually or in combination, on maize growth traits (plant height, LAI, plant dry weight and CGR), yield components (number of grains per ear, 100-grain weight, average grain weight, stover yield, grain yield, and total biological yield), and grain nutrient content (nitrogen, phosphorus, and potassium percentages) averaged over two growing seasons.

Severe salinity at the experimental site was confirmed (Table 1), and is known to adversely affect germination, root development, nutrient uptake, and photosynthetic efficiency, ultimately resulting in reduced growth and yield (El Sabagh et al., 2021). High salt concentrations interfere with water balance and can cause ion toxicity in maize plants compared to other cereal crops (Shabana et al., 2025). Physiologically, SS induces chlorophyll degradation, reduced photosynthesis efficiency, decreased stomatal conductance, and increased levels of reactive oxygen species (ROS), which can damage plant tissues (El Sabagh et al., 2021). This results in smaller cobs, reduced numbers of kernels per ear, and reduced grain weights due to impaired carbohydrate movement, with yield losses ranging from moderate to severe depending on the level of SS and maize genotype (El Sabagh et al., 2021).

However, mitigation strategies such as chemical treatments, growth promoters, and hormones, as well as genetic and molecular approaches, can be effective in managing the impact of salinity. Of the aforementioned approaches, natural biostimulants such as AsA, tocopherol Toc, and Arg have been effective in enhancing the tolerance of maize to SS (Hassan et al., 2021; Khalil et al., 2022; Saravanan et al., 2026). Findings indicate that the application of the biostimulants, both singularly and in a combination, has been effective in alleviating the damage caused by salinity to growth, yield, and yield components, with the combined treatment being the most effective.

Ascorbic acid is notable for enhancing plant height, LAI, dry biomass, and CGR. Its function in cell division and cell wall loosening is beneficial for stem growth, as evidenced by increased plant heights (Al-Freeh et al., 2020). Moreover, AsA is beneficial for chlorophyll production while reducing oxidative stress (Hasanuzzaman et al., 2023). This enhances canopy growth, biomass production, and dry matter accumulation through increased photosynthesis (Khan and Malik, 2025; Al-Freeh et al., 2020). It is also beneficial for increased metabolic activity, thereby enhancing growth under both normal and stressful conditions, especially when accompanied by optimized irrigation (Elfky et al., 2025).

Foliar spray of α-tocopherol in drought or SS conditions increases the plant height by decreasing the oxidative damage and promoting cell division (Ali et al., 2020). α-Tocopherol maintains the integrity of chloroplast membranes, retains chlorophyll content (Sadaf et al., 2025), and increases leaf growth, thus enhancing the LAI and light interception. By limiting lipid peroxidation and maintaining the photosynthetic apparatus, Toc also increases biomass growth, nutrient uptake, and CGR in stressed conditions (Ali et al., 2020).

These growth increases are correlated with increases in N, P, and K content. Treatment with AsA, Toc, and Arg, separately or together, resulted in significant increases in grain number per ear, 100-grain weight, average grain weight, stover yield, grain yield, and total biological yield. These increases in growth and yield are due to enhanced vegetative growth, increased content of N, P, and K and increased setting of fruits, which are supported by antioxidant protection of reproductive organs (Bassuony et al., 2008; El Sabagh et al., 2021; Saravanan et al., 2026). AsA increases assimilate transport and kernel development (Khan and Fatima, 2025), Toc stabilizes physiological processes during grain development (Ali et al., 2020), and Arg increases carbohydrate content and supports reproductive processes (Saravanan et al., 2026).

Furthermore, these biostimulants can increase nutrient content in grains. AsA, Toc, and Arg can increase grain protein content under SS by protecting enzymes used in nitrate reduction and amino acid synthesis (El-Bassiouny et al., 2017; Saravanan et al., 2026). These biostimulants can increase phosphorus uptake and translocation in plants by promoting root development and protecting membranes (El Sabagh et al., 2021). These biostimulants can maintain potassium retention for efficient grain development and osmotic adjustment

(Yıldıztekin, 2021; Zamani et al., 2024). Arg can increase nutrient content in grains more efficiently than other amino acids due to its role in nitrogen metabolism, polyamines, nitric oxide production, and ion transport regulation, while Toc can indirectly increase nutrient content in grains through membrane protection (Zamani et al., 2024; Saravanan et al., 2026).

The simultaneous use of AsA, Toc, and Arg takes advantage of their cooperative actions on different stress-signaling pathways, thereby offering a multi-faceted antioxidant protection: AsA acts as an ROS scavenger, Toc maintains membrane fluidity and inhibits lipid peroxidation, while Arg helps activate antioxidant enzymes via polyamine- and nitric oxide-mediated pathways (Tuna et al., 2013; El Sabagh et al., 2021; Saravanan et al., 2026). This multi-faceted approach enhances osmotic adjustment, ion balance, photosynthetic activity, and chlorophyll content, thereby promoting growth and productivity under salinity (El Sabagh et al., 2021; Hasanuzzaman et al., 2023; Mohamad et al., 2023; Saravanan et al., 2026).

As illustrated in Figure 6, foliar use of AsA, Toc and Arg (1 g L^{-1}), whether applied individually or in combination, exerted a positive influence on growth attributes such as plant height, LAI, plant dry weight, and CGR as well as yield components, including grains per ear, 100-grain weight, grain weight, total grain yield, stover yield, and biological yield, in addition to grain nutrient contents (N, P and K) of maize cultivated under SS conditions. Notably, the combined treatment was more effective than the individual applications.

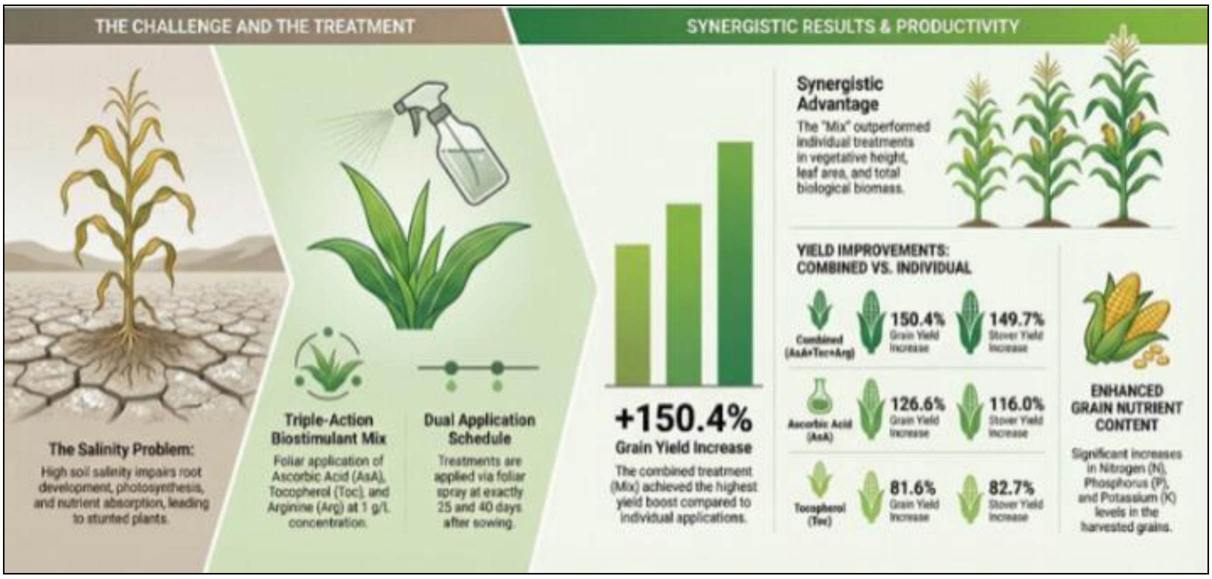

Figure 6. Graphical abstract depicting the beneficial effects of foliar application of ascorbic acid, tocopherol, and arginine (1 g L^{-1}), applied individually or in combination, on maize growth parameters, yield components, and grain nutrient composition under salinity stress conditions.

CONCLUSIONS

The results revealed that the application of ascorbic acid, tocopherol, and arginine, either singularly or in combination, reduced the adverse impacts of SS on the growth and productivity of maize. Simultaneously, the combined application of these compounds showed a synergistic effect, i.e., their combined application was found to be more effective in improving all the growth and yield-related traits.

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REFERENCES

Al-Freeh, L.M., Alshummary, A.M., Alabdulla, S.A., 2020. *Effect of foliar spray with ascorbic acid on two maize cultivars grown under saline soil.* International Journal of Agricultural and Statistical Sciences, 16(1): 2073-2078. https://connectjournals.com/03899.2020.16.2073

Ali, Q., Tariq Javed, M., Haider, M.Z., Habib, N., Rizwan, M., Perveen, R., Shafaqat Ali, S., Alyemeni, M.N., El-Serehy, H.A., Al-Misned, F.A., 2020. *α-Tocopherol foliar spray and translocation mediate growth, photosynthetic pigments, nutrient uptake, and oxidative defense in maize (Zea mays L.) under drought stress*. Agronomy, 10(9): 1-27. https://doi.org/10.3390/agronomy10091235

Bassuony, F.M., Hassanein, R.A., Baraka, D.M., Khalil, R.R., 2008. *Physiological effects of nicotinamide and ascorbic acid on Zea mays plant grown under SS II-Changes in nitrogen constituent, protein profiles, protease enzyme and certain inorganic cations.* Australian Journal of Basic and Applied Sciences, 2(3): 350-359.

Dane, J.H., and Topp, C.G., 2020. *Methods of soil analysis, Part 4: Physical methods*. John Wiley & Sons.

Dekhil, M.A.I., 2021. *Alleviating the impact of salinity stress on maize plants using some antioxidants*. Doctoral thesis, Department of Environmental Agricultural Sciences, Institute of Environmental Studies and Research, Ain Shams University, Egypt.

Duncan, D.B., 1955. *Multiple range and multiple F-test*. Biometrics, 11: 1. https://doi.org/10.2307/3001478

El-Beltagi, H.S., Ahmad, I., Basit, A., Shehata, W.F., Hassan, U., Shah, S.T., Haleema, B., Abdullah Jalal, A., Amin, R., Khalid, M.A., Fahad Noor, F., Mohamed, H.I., 2022. *Ascorbic acid enhances growth and yield of sweet peppers (Capsicum annum) by mitigating salinity stress.* Gesunde Pflanzen, 74(2): 423-433. https://doi.org/10.1007/s10343-021-00619-6

El-Beltagi, H.S., El-Nady, M.F., Al-Daej, M.I., El-Naqma, K.A., Rezk, A.A., El-Afry, M.M., Shehata, W.F., Ismail, A.M., Eltonoby, W.F., Metwaly, M.M.S., 2024. *Exogenous application of manganese and arginine alleviates the adverse effects of SS on pea (Pisum sativum L.).* Cogent Food & Agriculture, 10(1): 1-21. https://doi.org/10.1080/23311932.2024.2389445

El-Beltagi, H.S., El Nady, M.F., Mahmoud, A., Metwaly, M.M.S., 2026. *Ameloration of salinity stress in tomato by foliar sprays of ascorbic acid and proline*. Bioagro, 38(1): 407-420. https://doi.org/10.51372/bioagro381.2

Elfky, K.E.A., Eryan, N.L., Elsmahy, B.E., El Mansoury, M.A., 2025. *Impact of irrigation intervals and spraying with ascorbic acid and salicylic acid on morpho-physiological, quality and yield traits of maize (Zea mays L.)*. Zagazig Journal of Agricultural Research, 52(4): 751-764.

El Sabagh, A., Çiğ, F., Seydoşoğlu, S., Battaglia, M.L., Javed, T., Iqbal, M.A., Awad, M., 2021. *Salinity stress in maize: Effects of stress and recent developments of tolerance for improvement*. Cereal Grains, 1: 213. https://doi.org/10.5772/intechopen.98745

FAO, 2005. *Global network on integrated soil management for sustainable use of salt-affected soils*. FAO Land and Plant Nutrition Management Service, Rome, Italy. http://www.fao.org/ag/agl/agll/spush

Farooq, M., Hussain, M., Abdul Wakeel, A., Siddique, K.H.M., 2015. *Salt stress in maize: effects, resistance mechanisms, and management. A review*. Agronomy for Sustainable Development: 461-481. https://doi.org/10.1007/s13593-015-0287-0

Fatima, H., Khan, A., Nadeem, M., Khalofah, A., Abbas, T., 2025. *Induction of salinity tolerance in maize (Zea mays L.) by exogenous application of ascorbic acid and gibberellic acid.* Scientific Reports, 15(1): 38273. https://doi.org/10.1038/s41598-025-22174-0

Gardener, F.P., Pearce, R.B., Mitcheel, R.L., 1985. *Growth and Development*. In: Physiology of Crop Plants, Iowa State Univ. Press.

Hasanuzzaman, M., Raihan, M.R.H., Alharby, H.F., Al-Zahrani, H.S., Alsamadany, H., Alghamdi, K.M., Ahmed, N., Nahar, K., 2023. *Foliar application of ascorbic acid and tocopherol in conferring salt tolerance in rapeseed by enhancing K+/Na+ homeostasis, osmoregulation, antioxidant defense, and glyoxalase system.* Agronomy, 13(2): 1-20. https://doi.org/10.3390/agronomy13020361

Hassan, A., Amjad, S.F., Saleem, M.H., Yasmin, H., Imran, M., Riaz, M., Ali, Q., Joyia, F.A., Ahmed, S., Ali, S., Alyemeni, M.N., 2021. *Foliar application of ascorbic acid enhances SS tolerance in barley (Hordeum vulgare L.) through modulation of morpho-physio-biochemical attributes, ions uptake, osmo-protectants and stress response genes expression.* Saudi Journal of Biological Sciences, 28(8): 4276-4290. https://doi.org/10.1016/j.sjbs.2021.03.045

Khalil, R., Yusuf, M., Bassuony, F., Haroun, S., Gamal, A., 2022. *Alpha-tocopherol reinforce selenium efficiency to ameliorates salt stress in maize plants through carbon metabolism, enhanced photosynthetic pigments and ion uptake*. South African Journal of Botany, 144: 1-9. https://doi.org/10.1016/j.sajb.2021.08.033

Khan, F.I., and Fatima, T., 2025. *Effect of Antioxidant (Ascorbic Acid, AsA) on Maize (Zea mays L.) Growth.* International Journal of Innovation and Applied Studies, 46(4): 629-637.

Khan, F.I., and Malik, S., 2025. *Effect of Exogenously Applied Vitamin C (Ascorbic Acid) as Foliar Spray on the Growth of Maize (Zea mays L.).* International Journal of Innovation and Applied Studies, 47(2): 138-146.

Lalarukh, I., Wang, X., Amjad, S.F., Hussain, R., Ahmar, S., Mora-Poblete, F., Abdel-Hafez, S.H., Fawzy, M.A., Abbas, M.H., Abdelhafez, A.A., Datta, R., 2022. *Chemical role of α-tocopherol in salt stress mitigation by improvement in morpho-physiological attributes of sunflower (Helianthus annuus L.).* Saudi Journal of Biological Sciences, 29(3): 1386-1393. https://doi.org/10.1016/j.sjbs.2021.11.027

Meng, Y., Wang, Z., Zong, R., Zhang, J., Ma, Z., Guo, L., 2022. *Effects of biodegradable film resilience and irrigation amounts on film degradation and maize growth in arid northwest China*. European Journal of Agronomy, 140, 126588. https://doi.org/10.1016/j.eja.2022.126588

Mohamad, S.M., Darwish, M.M.B., Shahed, H.M., Abu Shosha, A.M., 2023. *Spraying maize with salicylic and ascorbic acids to improve physiological traits and productivity under water stress conditions.* Journal of Plant Production, 14(5): 233-243. https://doi.org/10.21608/jpp.2023.201140.1229

Radford, P.J., 1967. *Growth analysis formulae-their use and abuse*. Crop Sciences, 7(3): 171-175.

Sadaf, U.S., Shah, S., Jamal, A., Mihoub, A., Farhan Saeed, M., Ahmad, I., Radicetti, E., Zia, A., Mastinu, A., Černý, J., 2025. *Foliar application of ascorbic acid and α-tocopherol enhances salinity tolerance in Hordeum vulgare L. by regulating antioxidant enzymatic activity and improving physiological and biochemical responses*. Journal of Crop Health, 77(4): 1-21. https://doi.org/10.1007/s10343-025-01182-0

Saravanan, K., Dhanapal, S., Punithavathi, G., Afrith, W., Kiruthiga, N., Deepa Joan of Arc, C., 2026. *Exogenous arginine as a potential biostimulant for enhancing SS tolerance in maize (Zea mays L.).* Russian Journal of Plant Physiology, 73(1), 11. https://doi.org/10.1134/S1021443725605300

Shabana, M.M., Elhawat, N., El-Aziz, M.A.A., Elghany, S.A., Badawy, A.F., Alshaal, T., 2025. *Optimizing soil health and maize yield under SS with compost and sulfur nanoparticles*. Plants, 14(11): 1-26. https://doi.org/10.3390/plants14111661

Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., 2020. *Methods of soil analysis, part 3: Chemical methods*. John Wiley & Sons.

Tarolli, P., Luo, J., Park, E., Barcaccia, G., Masin, R., 2024. *Soil salinization in agriculture: mitigation and adaptation strategies combining nature-based solutions and bioengineering*. iScience, 27: 1-9. https://doi.org/10.1016/j.isci.2024.108830

Tuna, A.L., Kaya, C., Altunlu, H., Ashraf, M., 2013. *Mitigation effects of non-enzymatic antioxidants in maize ('Zea mays' L.) plants under salinity stress.* Australian Journal of Crop Science, 7(8): 1181-1188.

Walinga, I., Van Der Lee, J., Houba, V.J., Vanvark, W., Novozamsky, I., 2013. *Plant analysis manual*. Springer-Science: 1-239.

Yıldıztekin, M., 2021. *Ameliorative effects of exogenous ascorbic acid and potassium nitrate on antioxidant defense system and mineral nutrient uptake in tomatoes under salt stress.* Pakistan Journal of Botany, 53(2): 401-407. https://doi.org/10.30848/pjb2021-2%288%29

Zamani, E., Bakhtari, B., Razi, H., Hildebrand, D., Moghadam, A., Alemzadeh, A., 2024. *Comparative morphological, physiological, and biochemical traits in sensitive and tolerant maize genotypes in response to salinity and Pb stress.* Scientific Reports, 14(1), 31036. https://doi.org/10.1038/s41598-024-82173-5