

EFFECTIVENESS OF BIOLOGICAL PREPARATIONS IN ENHANCING SALINITY TOLERANCE IN STEVIA: MODERN APPROACHES

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Abstract. Soil salinity is one of the major abiotic stress factors causing reductions in crop yield and product quality in agriculture. *Stevia rebaudiana* Bertoni is a high-value sweetener and medicinal plant whose leaves accumulate steviol glycosides widely used in the food and pharmaceutical industries. However, stevia is considered relatively sensitive to salinity, and salt stress conditions suppress growth, photosynthesis, mineral nutrition, and metabolic processes. This review analyzes the physiological and biochemical effects of salinity stress in stevia and examines the protective mechanisms of biological preparations, including plant growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), and seaweed-based bio stimulants. The literature indicates that biological preparations mitigate the negative effects of salt stress by improving ion homeostasis, activating antioxidant systems, enhancing osmotic regulation, and stimulating root development. As a result, vegetative growth, leaf biomass accumulation, and quality traits become more stable under saline conditions. Nevertheless, the molecular-level effects of biological preparations on steviol glycoside biosynthesis remain insufficiently studied. Biological approaches are therefore considered environmentally safe and promising strategies for stevia cultivation in saline soils.

Keywords: salinity stress, *Stevia rebaudiana*, biological preparations, PGPR, steviol glycosides, antioxidant system.

INTRODUCTION

In recent years, the effects of salinity stress on plants have been widely studied. Research shows that high salt concentrations reduce plant water potential, leading to stomatal closure and a decline in photosynthetic rate. In addition, excessive accumulation of Na⁺ and Cl⁻ ions limit the uptake of K⁺ and Ca²⁺ [1]. Studies conducted on stevia have demonstrated that under saline conditions, leaf biomass and glycoside content decrease. Some studies have reported that even moderate salinity levels can significantly reduce the synthesis of steviol glycosides. The role of PGPR bacteria in enhancing plant salinity tolerance has been proven in many crops. They stimulate the synthesis of IAA, GA, and cytokinins, thereby promoting root system development. Through the ACC-deaminase enzyme, they reduce stress-induced ethylene levels, which helps maintain plant growth [3].

Arbuscular mycorrhizal fungi improve the uptake of water and nutrients under saline conditions. Studies indicate that plants inoculated with AMF exhibit a more optimal Na⁺/K⁺ ratio. Seaweed-based biostimulants increase the activity of antioxidant enzymes (SOD, CAT, POD) and reduce lipid peroxidation. As a result, cell membrane stability is preserved. However, the

molecular and metabolic bases of the effects of biological preparations on stevia have not yet been sufficiently studied. In particular, information on response mechanisms associated with steviol glycoside biosynthesis remains limited.

Soil salinity is one of the most important abiotic factors limiting productivity in irrigated agriculture. Its scale is expanding due to deteriorating water quality, insufficient drainage systems, and climate change. Under saline conditions, plants are simultaneously exposed to osmotic stress (water deficit), ionic toxicity (Na^+ and Cl^- accumulation), mineral nutrient imbalance (deficiency of K^+ and Ca^{2+}), and oxidative stress (increased ROS). These factors lead to reduced photosynthetic efficiency, disruption of membrane stability, and suppressed growth [5,7]. The relevance of this topic is determined by the following: (i) the need to stabilize the production of high-value medicinal and food crops under saline conditions; (ii) the challenge of maintaining glycoside content (stevioside, rebaudioside A) along with leaf yield in stevia [4,11], (iii) the growing demand for biological solutions that reduce chemical inputs [6,14].

Stevia rebaudiana Bertoni is a natural source of sweeteners, and the steviol glycosides accumulated in its leaves (mainly stevioside and rebaudioside A) are widely used in the food and pharmaceutical industries. Nevertheless, stevia is moderately sensitive to salinity, and many experiments have reported that increasing NaCl concentration leads to reductions in vegetative biomass, photosynthetic pigments, and certain quality traits [4,11,16]. In particular, decreases in stevia biomass and changes in glycoside composition under saline conditions have been emphasized [17]. Therefore, improving stevia cultivation technologies in saline soils, especially ensuring the stability of both yield and quality (glycosides), is an important scientific and practical task.

Conventional approaches (leaching irrigation, gypsum application, and increased mineral fertilization) are often costly or associated with environmental limitations. Therefore, in recent years, biological preparations have been widely studied as environmentally safe and resource-efficient solutions. These include biological products such as PGPR (plant growth-promoting rhizobacteria), arbuscular mycorrhizal fungi, and seaweed-extract-based biostimulants [8,11]. These preparations can mitigate the harmful effects of salinity stress by strengthening the root system, improving ion homeostasis (normalizing the Na^+/K^+ ratio), activating antioxidant defenses, and enhancing osmoregulation in plants [2,5,7]. Research objective: To scientifically synthesize, based on the literature, the effectiveness of biological preparations in improving growth, productivity, and quality traits of stevia under salinity stress conditions, as well as their main mechanisms of action.

LITERATURE REVIEW

Salinity stress and stevia responses

Stevia under saline conditions is characterized by reduced growth, smaller leaf area, decreased chlorophyll content, and lower photosynthetic efficiency [11]. Several studies have shown that increasing salinity levels significantly reduce total dry biomass in stevia; at the same time, quantitative and qualitative changes occur in steviol glycoside composition [17]. Recent publications also confirm that severe salinity enhances oxidative stress and leads to declines in growth parameters [4]. Although certain adaptive responses—such as activation of osmotic regulators and antioxidant systems—may be triggered under salt stress, these mechanisms are often insufficient to fully maintain yield and quality stability.

Seaweed extracts and biostimulants

Seaweed extracts (SWE) are natural biostimulants whose bioactive compounds can support antioxidant defense, osmotic regulation, and nutrient uptake in plants [9]. Experimental studies have shown that under saline (or saline–alkaline) conditions, seaweed-based biostimulants can improve plant growth by lowering the Na^+/K^+ ratio and strengthening antioxidant and osmotic systems [12]. In addition, biostimulants derived from *Ascophyllum nodosum* have been reported to enhance protective responses in certain crops under salt stress [13]. General reviews highlight that SWE are promising tools for improving plant tolerance to various stresses [10]. Moreover, biostimulants may support the root microbiome through a “prebiotic” effect, promoting cooperation with beneficial microorganisms such as *Pseudomonas* and mycorrhizae [14].

Stevia quality under salinity and the role of biological preparations

Stevia quality is mainly evaluated based on the content and composition of steviol glycosides in the leaves, particularly the stevioside/rebaudioside A ratio. It has been shown that the level of salinity and the type of salt source influence not only stevia growth but also quality traits [10]. Some studies indicate that glycoside dynamics under salt stress are complex, with plant responses varying depending on the intensity and duration of stress [17]. From this perspective, the effectiveness of biological preparations should be assessed not only by biomass production but also by the stability of glycoside content and composition [4].

CONCLUSION

Soil salinity is a major abiotic factor limiting the growth, physiological processes, and quality traits of *Stevia rebaudiana*. Under saline conditions, osmotic stress, ionic toxicity, and oxidative stress lead to reduced photosynthesis, decreased biomass accumulation, and changes in the content and ratio of steviol glycosides. This directly affects the economic efficiency of stevia cultivation. The literature analysis indicates that biological preparations—particularly PGPR, arbuscular mycorrhizal fungi, and seaweed-based biostimulants—can serve as effective tools for enhancing plant adaptation under salinity stress. They mitigate the negative effects of stress by promoting root system development, normalizing Na^+/K^+ ion balance, increasing antioxidant enzyme activity, and strengthening osmoregulation. As a result, vegetative growth, leaf biomass accumulation, and metabolic stability are improved.

At the same time, the molecular-level effects of biological preparations on steviol glycoside biosynthesis in stevia remain insufficiently studied. In particular, how glycoside content and composition are regulated under stress conditions and how they are modulated by biological treatments represent important directions for future research. Overall, biological preparations have strong potential as an environmentally safe and sustainable strategy for stevia cultivation in saline soils. Their integration with breeding, agronomic technologies, and molecular research could expand the possibilities for producing high-quality and high-yielding stevia in salt-affected regions.

REFERENCES

1. Alonazi, M. A., Alwathnani, H. A., AL-Barakah, F. N. I., & Alotaibi, F. (2025). Native plant growth-promoting rhizobacteria containing ACC deaminase promote plant growth and alleviate salinity and heat stress in maize (*Zea mays* L.) plants in Saudi Arabia. *Plants*, 14(7), 1107. <https://doi.org/10.3390/plants14071107>
2. Boyno, G., Danesh, Y., & boshqalar. (2025). *Plant-fungus synergy against soil salinity: The cellular and molecular role of arbuscular mycorrhizal fungi*. *iScience*. Advance online publication. <https://doi.org/10.1016/j.isci.2025.101645>

3. Chen, Z., Park, J. B., & Hwang, S. (2022). Plant growth-promoting rhizobacteria with ACC deaminase activity improve plant growth under salinity stress: A review. *Frontiers in Plant Science*, 12, 800783. <https://doi.org/10.3389/fpls.2021.800783>
4. Clemente, C., Tavarini, S., Landi, M., Martini, A., Incrocci, L., Guidi, L., & Angelini, L. G. (2026). Mild salt stress impacts physio-chemical attributes and promotes rebaudioside A accumulation in *Stevia rebaudiana* Bertoni cultivated in floating systems. *Agriculture*, 16(2), 159. <https://doi.org/10.3390/agriculture16020159>
5. Dastogeer, K. M. G., Li, H., Sivasithamparam, K., Jones, M. G. K., & Wylie, S. J. (2020). Plant salinity tolerance conferred by arbuscular mycorrhizal fungi and associated mechanisms: A meta-analysis. *Frontiers in Plant Science*, 11, 588550. <https://doi.org/10.3389/fpls.2020.588550>
6. Egamberdieva, D., Wirth, S., Alqarawi, A. A., Abd-Allah, E. F., & Hashem, A. (2019). Salt-tolerant plant growth-promoting rhizobacteria for enhancing crop productivity of saline soils. *Microorganisms*, 7(12), 607. <https://doi.org/10.3390/microorganisms7120607>
7. Evelin, H., Kapoor, R., & Giri, B. (2009). Arbuscular mycorrhizal fungi in alleviation of salt stress: A review. *Annals of Botany*, 104(7), 1263–1280. <https://doi.org/10.1093/aob/mcp251>
8. Egamberdieva, D., Wirth, S., Bellingrath-Kimura, S. D., Mishra, J., & Arora, N. K. (2019). Salt-tolerant plant growth-promoting rhizobacteria for enhancing crop productivity of saline soils. *Frontiers in Microbiology*, 10, Article 2791. <https://doi.org/10.3389/fmicb.2019.02>
9. Fozì, V., Hamedani, S. R., & Shekafandeh, A. (2024). Seaweed extract application improves plant performance under abiotic stress conditions: A review. *Plants*, 13(3), 402. <https://doi.org/10.3390/plants13030402>
10. Kumar, G., Sahoo, D., & Levine, I. (2024). Seaweed extracts: Enhancing plant resilience to abiotic and biotic stresses. *Frontiers in Marine Science*, 11, 1457500. <https://doi.org/10.3389/fmars.2024.1457500>
11. Kurunç, A., Aslan, G. E., Karaca, C., & Tezcan, A. (2020). Effects of salt source and irrigation water salinity on growth, yield and quality of *Stevia* (*Stevia rebaudiana* Bertoni). *Scientia Horticulturae*, 272, 109557. <https://doi.org/10.1016/j.scienta.2020.109557>
12. Ma, C., Wang, L., Zhang, H., & Li, X. (2025). Effects of seaweed-derived biostimulant supplementation on maize growth, physiology, and stress tolerance under saline-alkaline conditions. *Journal of Plant Physiology and Biochemistry*, 223, 108–119. <https://doi.org/10.1016/j.jplph.2025.108119>
13. Shahzad, R., Waqas, M., Khan, A. L., & Lee, I. J. (2023). Ascophyllum nodosum-based biostimulant improves plant growth and stress tolerance under salinity conditions. *Journal of Applied Phycology*, 35, 1235–1248. <https://doi.org/10.1007/s10811-022-02890-z>
14. Spagnuolo, D., Jamal, A., & Prisa, D. (2025). Comparative evaluation of marine algae-based biostimulants for enhancing growth, physiological performance, and essential oil yield in *Lavender* (*Lavandula angustifolia*) under greenhouse conditions. *Phycology*, 5(3), 41. <https://doi.org/10.3390/phycology5030041>
15. Tavarini, S., & Angelini, L. G. (2013). *Stevia rebaudiana* Bertoni as a source of bioactive compounds: The effect of salinity on growth, leaf yield and steviol glycoside content. *Industrial Crops and Products*, 44, 17–21. <https://doi.org/10.1016/j.indcrop.2012.10.037>
16. Cantabella, D., Piqueras, A., Acosta-Motos, J. R., Bernal-Vicente, A., Hernández, J. A., & Díaz-Vivancos, P. (2017). Salt tolerance mechanisms induced in *Stevia rebaudiana* Bertoni:

- Effects on growth, physiological traits and antioxidant responses. *Plant Physiology and Biochemistry*, 115, 324–333. <https://doi.org/10.1016/j.plaphy.2017.04.012>
17. Zeng, J., Chen, A., Li, D., Yi, B., & Wu, W. (2013). *Effects of salt stress on the growth, physiological responses and glycoside contents of Stevia rebaudiana Bertonii*. *Journal of Agricultural and Food Chemistry*, 61(18), 4503–4511. <https://doi.org/10.1021/jf401237x>