

# Salt Stress Tolerance in Medicinal and Aromatic Plants: A Review

## Abstract

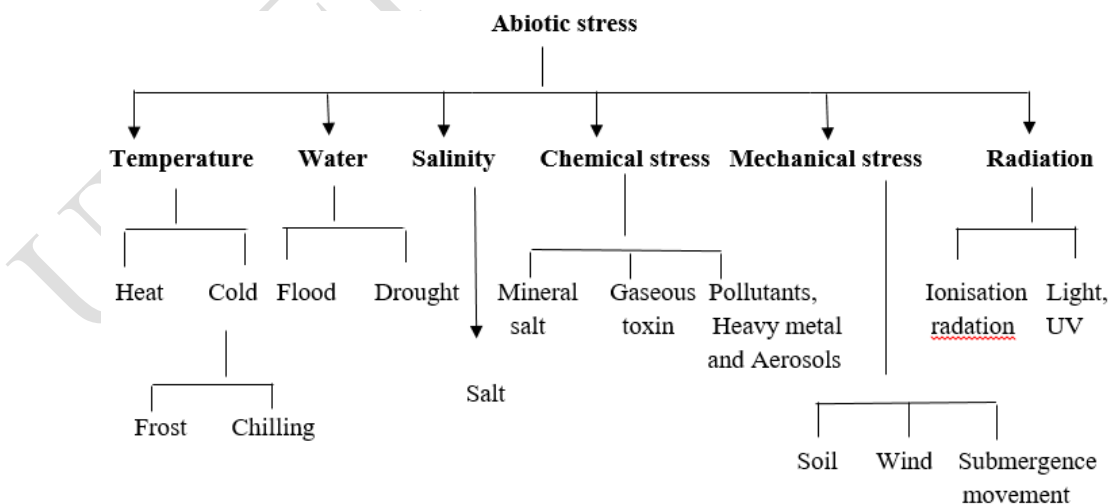
Soil salinity is a globally pervasive issue, significantly affecting crop productivity and quality. This review provides a comprehensive overview of salt stress tolerance in medicinal and aromatic plants, plants known for their unique metabolic capabilities and resilience to abiotic stress. The adverse impact of salt stress on plant development, growth, and chemical composition is examined, emphasizing the specific effects on medicinal and aromatic plants, such as reduced biomass, altered yield, and modification of chemical composition. We delve into the complex responses exhibited by plants under salt stress, including physiological, biochemical, and molecular mechanisms. Physiological responses such as osmotic adjustment and ion homeostasis, biochemical responses including antioxidant production and compatible solute synthesis, and molecular responses like the upregulation of salt stress-responsive genes and hormone modulation, all contribute to salt stress tolerance. Understanding these intricate mechanisms offers valuable insights into the plants' resilience under salt stress. This review also discusses strategies to enhance salt stress tolerance in medicinal and aromatic plants, encompassing breeding and genetic modification, management strategies, and the utilization of beneficial soil microbes. The potential of selective breeding and genetic engineering in developing salt-tolerant plants is explored, along with the implementation of efficient irrigation systems and the use of salt-tolerant rootstocks. Additionally, the potential role of beneficial soil microbes such as mycorrhizal fungi and plant growth-promoting rhizobacteria in alleviating salt stress is highlighted. Lastly, we present potential future directions and applications for this research. The findings and strategies elaborated upon in this review have far-reaching implications, including the improvement of salt stress tolerance in other crops, promoting sustainable agriculture in saline soils, and potential therapeutic implications due to altered biochemical composition under salt stress. The continuation of research in this field is critical to tackling soil salinity challenges and maximizing the medicinal and aromatic plants' potential under salt stress. This review underscores the importance of studying salt stress tolerance mechanisms in medicinal and aromatic plants to contribute to sustainable agricultural practices and the advancement of the pharmaceutical industry.

**Keywords:** *Salt-stress, Tolerance, Medicinal, Aromatic, Agriculture*

## Introduction

Salt stress, a type of abiotic stress, is defined as the negative physiological effects experienced by plants due to high salt concentration in the soil, typically resulting from irrigation practices or natural processes such as sea water intrusion and mineral weathering [1]. Salt stress encompasses two main components: an immediate osmotic stress that inhibits plant growth and a longer-term ionic stress resulting from the accumulation of toxic ions in the plant tissue, primarily sodium

and chloride [2]. Salt stress poses a serious and increasing threat to agriculture worldwide. Approximately 20% of the world's irrigated lands and nearly 50% of all arable lands are affected by salinity [3]. It has been estimated that by 2050, more than 50% of arable land worldwide could be affected by salinity [4]. The impact of salinity stress on crop productivity is substantial, leading to reduced yield, quality, and economic value. For example, wheat yield can decrease by more than 50% under moderate salt stress conditions [5]. Medicinal and aromatic plants play significant roles in various sectors, including healthcare, cosmetics, and food industry, due to their therapeutic properties and flavors [6]. They serve as a rich source of bioactive compounds like essential oils, antioxidants, and other secondary metabolites with antimicrobial, anti-inflammatory, and antitumor activities [7]. Some well-known medicinal and aromatic plants include lavender, rosemary, and thyme, which have been extensively used in traditional medicine for their healing properties. For instance, lavender is known for its calming effect, rosemary for its potential to improve memory, and thyme for its antimicrobial properties [8]. These plants also contribute significantly to the economy, particularly in countries where they are cultivated extensively. Just like other crops, medicinal and aromatic plants are not immune to the detrimental effects of salt stress. High salinity can lead to a reduction in plant growth, biomass, and yield, affecting the overall productivity of these plants [9]. Moreover, salt stress can alter the composition of the bioactive compounds in these plants. For instance, studies have reported changes in essential oil content and composition in rosemary and lavender under salt stress conditions [10]. However, it is noteworthy that some medicinal and aromatic plants exhibit considerable tolerance to salt stress, and understanding these mechanisms could offer ways to improve salt tolerance in other plant species [11]. Given the increasing threat of soil salinization and its impact on plant productivity, understanding the mechanisms behind salt stress tolerance in medicinal and aromatic plants has gained significant importance. This review aims to elucidate these mechanisms and provide a comprehensive understanding of how these plants cope with salt stress. Furthermore, the review intends to highlight potential strategies for enhancing salt stress tolerance in these economically and therapeutically important plants. By doing so, this review hopes to contribute to sustainable agricultural practices and the continued cultivation of medicinal and aromatic plants in saline soils.



**Fig 1:** Several abiotic stress signalling affect plants [12].

## **The Effect of Salt Stress on Plants**

One of the earliest responses to salinity is osmotic stress, which is caused by the high concentration of salt in the soil solution [13]. This high salt concentration reduces the soil water potential, making it more difficult for plants to extract water. This results in an immediate inhibition of root and shoot growth [14]. The osmotic stress caused by high soil salinity can induce a series of metabolic and physiological changes in plants, such as reducing photosynthesis and transpiration rates [15]. Ionic toxicity is a subsequent effect of salinity that occurs when the plant absorbs excessive sodium and chloride ions. These ions accumulate over time and can reach toxic levels, causing cellular damage [16]. Sodium ions, in particular, are known to interfere with potassium uptake and disrupt essential metabolic processes, leading to cellular dysfunction [17]. Chloride ions, while less toxic than sodium ions, can also cause toxicity symptoms at high concentrations [18]. Salinity stress often leads to nutrient imbalance in plants. High concentrations of sodium in the soil solution can interfere with the absorption of other essential cations such as potassium, calcium, and magnesium, which can cause nutrient deficiencies and impair plant metabolic process [19]. For example, potassium, which plays a crucial role in maintaining cell turgor, enzyme activation, and stomatal opening, can be severely affected by high sodium concentrations [20].

## **Salt Stress on the Growth of Medicinal and Aromatic Plants**

One of the significant effects of salt stress in medicinal and aromatic plants is a reduction in plant biomass. High salt levels can lead to a decrease in both root and shoot growth, resulting in smaller plant size [21]. For instance, a study on the effects of salinity stress on rosemary (*Rosmarinus officinalis*) demonstrated that increased salinity led to a significant decrease in the plant's total biomass [22]. Similarly, salt stress reduced the total dry weight of lavender plants (*Lavandula angustifolia*) in a dose-dependent manner [23]. In addition to biomass reduction, salinity stress can lead to decreased yield in medicinal and aromatic plants. The reduced plant growth due to osmotic stress, ionic toxicity, and nutrient imbalance ultimately results in lower flower and leaf yield, the parts of the plant most commonly used for their medicinal properties and aromatic oils [24]. For instance, high salt levels significantly reduced the flower yield of chamomile (*Matricaria chamomilla*), a popular medicinal and aromatic plant [25]. Apart from growth and yield, salt stress can significantly alter the chemical composition of medicinal and aromatic plants. Changes in the concentration of bioactive compounds, including essential oils and antioxidants, have been observed under high salinity conditions [26]. For instance, rosemary plants grown under saline conditions demonstrated changes in their essential oil composition, with an increase in certain compounds and a decrease in others [27]. Similarly, in lavender plants, salt stress caused a significant alteration in the essential oil profile, affecting its quality [28].

## **Mechanisms of Salt Stress Tolerance in Plants**

Plants, being sessile organisms, have developed a variety of mechanisms to deal with environmental stressors such as high salinity [29]. These mechanisms range from physiological and biochemical responses to changes at the molecular level. They are often interconnected, and collectively contribute to a plant's ability to tolerate and adapt to salt stress. One of the primary physiological responses to salt stress is osmotic adjustment. This involves the accumulation of organic and inorganic solutes in the plant cells to maintain cell turgor and water uptake under high external salt concentrations [30]. This allows the plant to continue growing even under osmotic stress. For example, proline, a common osmolyte, has been found to accumulate in various medicinal and aromatic plants under salt stress, aiding in osmotic adjustment [31]. Maintaining ion homeostasis is another important physiological response to salt stress. High concentrations of sodium ions can disrupt cellular ion balance, affecting metabolic processes and leading to toxicity [32]. To counter this, plants have developed mechanisms to exclude sodium from uptake, sequester excess sodium into the vacuole, or excrete it through salt glands or bladders [33]. These mechanisms help to maintain the cytosolic sodium concentration at non-toxic levels and ensure the optimal functioning of cellular processes.

### **Biochemical Responses to Salt Stress**

Salt stress leads to the production of reactive oxygen species (ROS), which can cause oxidative damage to proteins, lipids, and DNA [34]. To combat this, plants have a sophisticated antioxidant defense system, including enzymes like superoxide dismutase, catalase, and peroxidase, and non-enzymatic antioxidants like ascorbate and glutathione. These antioxidants scavenge ROS, thereby preventing cellular damage [35]. Compatible solutes, also known as osmolytes, are small organic compounds that can accumulate in high concentrations without disrupting cellular functions [36]. These include amino acids like proline, quaternary ammonium compounds like glycine betaine, and sugars like trehalose. Compatible solutes play a key role in osmotic adjustment and also protect cellular structures from damage caused by high salt concentrations [37].

### **Molecular Responses to Salt Stress**

At the molecular level, numerous genes are activated or repressed in response to salt stress. These salt stress-responsive genes encode proteins involved in a variety of functions, including ion transport, osmotic adjustment, antioxidant production, and signal transduction [38]. For instance, several genes involved in the synthesis of compatible solutes, such as P5CS (proline synthesis) and TPS (trehalose synthesis), have been identified to be upregulated under salt stress [39]. Plant hormones play a crucial role in the regulation of plant responses to salt stress. Abscisic acid (ABA) is one of the primary hormones involved in this process. ABA levels rise in response to salt stress, triggering stomatal closure to reduce water loss and activating stress-responsive genes [40]. Other hormones, such as ethylene, gibberellins, and jasmonates, also participate in the complex network of salt stress responses [41].

### **Salt Stress Tolerance in Medicinal and Aromatic Plants**

Numerous strategies have been proposed and implemented to enhance salt stress tolerance in medicinal and aromatic plants, ranging from traditional breeding techniques to modern genetic engineering approaches, from agronomic management to leveraging beneficial soil microbes.

These strategies aim at preserving and improving the productivity of these plants in saline conditions. Selective breeding or traditional breeding is a time-tested strategy for enhancing salt tolerance in plants [42]. By selecting parent plants with desirable traits, such as salt tolerance, and cross-breeding them, the resulting offspring may exhibit enhanced salt tolerance. This strategy has been utilized in several crops, including rice and wheat, with successful results [43]. However, the application of this strategy to medicinal and aromatic plants is still in its early stages and demands further research. Genetic engineering is a powerful tool that can directly introduce genes conferring salt tolerance into plants. For instance, overexpression of the gene *SOS1*, a sodium ion transporter, has been shown to enhance salt tolerance in transgenic *Arabidopsis* plants [44]. Similarly, transgenic approaches have been used to overexpress genes involved in the synthesis of compatible solutes, such as proline and trehalose, resulting in improved salt tolerance [45]. However, the use of genetic engineering in medicinal and aromatic plants must be cautiously approached due to potential impacts on the production of secondary metabolites. Efficient irrigation management is a practical approach to mitigate salt stress. For instance, the use of fresh water for leaching can help to reduce salt accumulation in the root zone [46]. However, the availability of fresh water is often a limiting factor, especially in arid and semi-arid regions. Alternative strategies, such as the use of treated wastewater or partial root-zone irrigation, can also be employed to manage salt stress [47]. The use of salt-tolerant rootstocks can confer salt tolerance to the grafted scion, as demonstrated in citrus and grapevines [48]. Similarly, the concept of companion planting, where salt-tolerant plant species are grown alongside salt-sensitive medicinal and aromatic plants, can also help to alleviate salt stress. The salt-tolerant plants can absorb excess salts, reducing the overall salinity of the soil and creating a more favorable environment for the growth of medicinal and aromatic plants [49]. Mycorrhizal fungi form symbiotic relationships with plant roots and can enhance plant tolerance to salt stress. They improve nutrient uptake, water absorption, and also secrete compounds that mitigate salt stress [50]. Studies have shown that mycorrhizal inoculation can enhance the growth and productivity of various medicinal and aromatic plants under salt stress [51].

Certain soil bacteria, known as PGPR, can promote plant growth and enhance salt tolerance. These bacteria can produce plant growth-promoting substances, induce systemic resistance, and facilitate nutrient uptake [52]. Recent studies have highlighted the potential of PGPR in enhancing salt tolerance in medicinal and aromatic plants [53].

Table 1: Role of PGPR on medicinal plants in amelioration of salt stress. PGPR refers to plant growth-promoting rhizobacteria.

<b>PGPR</b>	<b>Medicinal Plants</b>	<b>Effect</b>	<b>References</b>
<i>Bacillus megaterium</i>	<i>Catharanthus roseus</i>	Plant growth, enhanced secondary metabolites content	[54]
<i>Pseudomonas extremorientalis</i>	<i>Silybum marianum</i>	Increased biomass	[55]
<i>Azotobacter chroococcum</i>	<i>Catharanthus roseus</i>	Increased biomass	[54]
<i>Pseudomonas putida</i>	<i>Ocimum basilicum</i>	Increased biomass and secondary metabolites content	[56]
<i>Bacillus lentus</i>	<i>Ocimum basilicum</i>	Increased biomass	[56]

<i>Exiguobacteriumoxidotolerans</i>	<i>Bacopamonnieri</i>	Increased herb yield and bacoside-A content	[57]
<i>Bacillus pumilus</i>	<i>Bacopamonnieri</i>	Plant weight, bacoside-A content	[57]
<i>Bacillus coagulans</i>	<i>Glycyrrhizaglabra</i>	Increased biomass and secondary metabolites content	[58]
<i>Azospirillumbrasilense and Pseudomonas fluorescens</i>	<i>Catharanthusroseus</i>	Increased biomass and ajmalicine content	[54]
<i>Halomonas desiderata</i>	<i>Menthaarvensis</i>	Increased herb yield	[59]
<i>Exiguobacteriumoxidotolerans</i>	<i>Menthaarvensis</i>	Increased herb yield	[59]

### Future Directions and Potential Applications

The research on salt stress tolerance in medicinal and aromatic plants holds promising prospects for other crops, sustainable agriculture, and potential therapeutic applications. Below, we will delve deeper into these topics and elaborate on the future directions this research may take. The elucidation of salt stress tolerance mechanisms in medicinal and aromatic plants has implications beyond these specific plant groups. By understanding how these plants deal with salt stress, we can transfer this knowledge to improve salt stress tolerance in other crop plants [60]. For example, the genes identified in these plants responsible for osmotic adjustment, ion homeostasis, antioxidant production, and synthesis of compatible solutes could be potential targets for genetic engineering in other crops [61]. Similarly, the beneficial association between mycorrhizal fungi and plant growth-promoting rhizobacteria can be explored in other plant species [62]. The strategies identified to enhance salt stress tolerance in medicinal and aromatic plants hold significant potential for sustainable agriculture in saline soils. Given that soil salinity is a growing problem worldwide, these strategies could help increase crop productivity in affected areas [63]. For example, through selective breeding and genetic engineering, we could develop salt-tolerant plant varieties. These could be cultivated in saline soils, reducing the need for freshwater irrigation and mitigating the adverse environmental impact of conventional agriculture [64]. Moreover, the use of beneficial soil microbes could promote a more sustainable agriculture system by reducing the dependence on chemical fertilizers and pesticides [65]. Salt stress can induce changes in the biochemical composition of medicinal and aromatic plants, which can affect their therapeutic properties [66]. For instance, some studies have reported increased concentrations of essential oils and phenolic compounds – key contributors to the medicinal properties of these plants – under salt stress [67]. Understanding the influence of salt stress on the biosynthesis of these metabolites could enable us to manipulate growing conditions to maximize the production of desirable compounds. This offers exciting potential for the pharmaceutical industry, particularly in the production of natural health products [68].

### Conclusion

The review provides comprehensive insights into salt stress tolerance in medicinal and aromatic plants. It covers the detrimental effects of salt stress, physiological, biochemical, and molecular responses to salt stress, and strategies for enhancing salt tolerance. The implications of this

research extend beyond these plants, offering prospects for other crops, sustainable agriculture, and potential therapeutic applications. The possibility of using the knowledge in breeding salt-tolerant crops, adopting sustainable agricultural practices in saline soils, and leveraging changes in biochemical composition for therapeutic benefits are promising future directions. Continued exploration in this field is crucial for addressing soil salinity challenges and optimizing the benefits of medicinal and aromatic plants under such conditions.

## Reference

1. de Oliveira, A. B., Alencar, N. L. M., & Gomes-Filho, E. (2013). Comparison between the water and salt stress effects on plant growth and development. *Responses of organisms to water stress*, 4, 67-94.
2. Kang, S. M., Khan, A. L., Waqas, M., You, Y. H., Kim, J. H., Kim, J. G., ...& Lee, I. J. (2014). Plant growth-promoting rhizobacteria reduce adverse effects of salinity and osmotic stress by regulating phytohormones and antioxidants in *Cucumis sativus*. *Journal of Plant Interactions*, 9(1), 673-682.
3. Pitman, M. G., & Läuchli, A. (2002). Global impact of salinity and agricultural ecosystems. *Salinity: environment-plants-molecules*, 3, 20.
4. Mustafa, G., Akhtar, M. S., & Abdullah, R. (2019). Global concern for salinity on various agro-ecosystems. *Salt Stress, Microbes, and Plant Interactions: Causes and Solution: Volume 1*, 1-19.
5. Barakat, N., Laudadio, V., Cazzato, E., & Tufarelli, V. (2013). Antioxidant Potential and Oxidative Stress Markers in Wheat (*Triticum aestivum*) Treated with Phytohormones under Salt-Stress Condition. *International Journal of Agriculture & Biology*, 15(5).
6. Riaz, U., Iqbal, S., Sohail, M. I., Samreen, T., Ashraf, M., Akmal, F., ...& Akhter, R. M. (2021). A comprehensive review on emerging importance and economical potential of medicinal and aromatic plants (MAPs) in current scenario. *Pakistan Journal of Agricultural Research*, 34(2), 381-392.
7. Bourais, I., Elmarrkechy, S., Taha, D., Mourabit, Y., Bouyahya, A., El Yadini, M., ...& Iba, N. (2022). A review on medicinal uses, nutritional value, and antimicrobial, antioxidant, anti-inflammatory, antidiabetic, and anticancer potential related to bioactive compounds of *J. regia*. *Food Reviews International*, 1-51.
8. Cavanagh, H. M. A., & Wilkinson, J. M. (2002). Biological activities of lavender essential oil. *Phytotherapy research*, 16(4), 301-308.
9. Chaudhry, S., & Sidhu, G. P. S. (2022). Climate change regulated abiotic stress mechanisms in plants: A comprehensive review. *Plant Cell Reports*, 41(1), 1-31.

10. DehghaniBidgoli, R., Azarnezhad, N., Akhbari, M., &Ghorbani, M. (2019). Salinity stress and PGPR effects on essential oil changes in *Rosmarinusofficinalis* L. *Agriculture & Food Security*, 8(1), 1-7.
11. Hasanuzzaman, M., Nahar, K., Fujita, M., Ahmad, P., Chandna, R., Prasad, M. N. V., &Ozturk, M. (2013). Enhancing plant productivity under salt stress: relevance of poly-omics. *Salt stress in plants: signalling, omics and adaptations*, 113-156.
12. Akula R, Ravishankar GA. Influence of abiotic stress signals on secondary metabolites in plants. *Plant signaling & behavior*. 2011; 6(11):1720-1731.
13. Munns, R. (2002). Comparative physiology of salt and water stress. *Plant, cell & environment*, 25(2), 239-250.
14. Sheldon, A. R., Dalal, R. C., Kirchoff, G., Kopittke, P. M., &Menzies, N. W. (2017). The effect of salinity on plant-available water. *Plant and Soil*, 418, 477-491.
15. Reddy, A. R., Chaitanya, K. V., &Vivekanandan, M. (2004). Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of plant physiology*, 161(11), 1189-1202.
16. Tavakkoli, E., Fatehi, F., Coventry, S., Rengasamy, P., & McDonald, G. K. (2011). Additive effects of Na<sup>+</sup> and Cl<sup>-</sup> ions on barley growth under salinity stress. *Journal of Experimental Botany*, 62(6), 2189-2203.
17. Mahajan, S., &Tuteja, N. (2005). Cold, salinity and drought stresses: an overview. *Archives of biochemistry and biophysics*, 444(2), 139-158.
18. Tavakkoli, E., Rengasamy, P., & McDonald, G. K. (2010). High concentrations of Na<sup>+</sup> and Cl<sup>-</sup> ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress. *Journal of experimental botany*, 61(15), 4449-4459.
19. Wakeel, A., Farooq, M., Qadir, M., & Schubert, S. (2011). Potassium substitution by sodium in plants. *Critical reviews in plant sciences*, 30(4), 401-413.
20. Wang, M., Zheng, Q., Shen, Q., &Guo, S. (2013). The critical role of potassium in plant stress response. *International journal of molecular sciences*, 14(4), 7370-7390.
21. Cai, Z. Q., &Gao, Q. (2020). Comparative physiological and biochemical mechanisms of salt tolerance in five contrasting highland quinoa cultivars. *BMC plant biology*, 20(1), 1-15.

22. Sarmoum, R., Haid, S., Biche, M., Djazouli, Z., Zebib, B., & Merah, O. (2019). Effect of salinity and water stress on the essential oil components of rosemary (*Rosmarinus officinalis* L.). *Agronomy*, 9(5), 214.
23. Zhou, Y., Tang, N., Huang, L., Zhao, Y., Tang, X., & Wang, K. (2018). Effects of Salt Stress on Plant Growth, Antioxidant Capacity, Glandular Trichome Density, and Volatile Exudates of *Schizonepeta tenuifolia* Briq. *International journal of molecular sciences*, 19(1), 252.
24. Nawaz, K., Hussain, K., Majeed, A., Khan, F., Afghan, S., & Ali, K. (2010). Fatality of salt stress to plants: Morphological, physiological and biochemical aspects. *African Journal of Biotechnology*, 9(34).
25. Baghalian, K., Haghiry, A., Naghavi, M. R., & Mohammadi, A. (2008). Effect of saline irrigation water on agronomical and phytochemical characters of chamomile (*Matricaria recutita* L.). *Scientia Horticulturae*, 116(4), 437-441.
26. Baghalian, K., Haghiry, A., Naghavi, M. R., & Mohammadi, A. (2008). Effect of saline irrigation water on agronomical and phytochemical characters of chamomile (*Matricaria recutita* L.). *Scientia Horticulturae*, 116(4), 437-441.
27. El-Esawi, M. A., Elansary, H. O., El-Shanhorey, N. A., Abdel-Hamid, A. M., Ali, H. M., & Elshikh, M. S. (2017). Salicylic acid-regulated antioxidant mechanisms and gene expression enhance rosemary performance under saline conditions. *Frontiers in Physiology*, 8, 716.
28. Chrysargyris, A., Michailidi, E., & Tzortzakis, N. (2018). Physiological and biochemical responses of *Lavandula angustifolia* to salinity under mineral foliar application. *Frontiers in plant Science*, 9, 489.
29. Haggag, W. M., Abouzienna, H. F., Abd-El-Kreem, F., & El Habbasha, S. (2015). Agriculture biotechnology for management of multiple biotic and abiotic environmental stress in crops. *J. Chem. Pharm. Res*, 7(10), 882-889.
30. Jouyban, Z. (2012). The effects of salt stress on plant growth. *Technical Journal of Engineering and Applied Sciences*, 2(1), 7-10.
31. Jouyban, Z. (2012). The effects of salt stress on plant growth. *Technical Journal of Engineering and Applied Sciences*, 2(1), 7-10.
32. Tuteja, N. (2007). Mechanisms of high salinity tolerance in plants. *Methods in enzymology*, 428, 419-438.

33. Tanveer, M., & Shah, A. N. (2017). An insight into salt stress tolerance mechanisms of *Chenopodium album*. *Environmental Science and Pollution Research*, 24, 16531-16535.
34. Sharma, P., Jha, A. B., Dubey, R. S., & Pessarakli, M. (2012). Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. *Journal of botany*, 2012.
35. Battin, E. E., & Brumaghim, J. L. (2009). Antioxidant activity of sulfur and selenium: a review of reactive oxygen species scavenging, glutathione peroxidase, and metal-binding antioxidant mechanisms. *Cell biochemistry and biophysics*, 55(1), 1-23.
36. Peluso, G., Barbarisi, A., Savica, V., Reda, E., Nicolai, R., Benatti, P., & Calvani, M. (2001). Carnitine: an osmolyte that plays a metabolic role. *Journal of cellular biochemistry*, 80(1), 1-10.
37. Hussain Wani, S., Brajendra Singh, N., Haribhushan, A., & Iqbal Mir, J. (2013). Compatible solute engineering in plants for abiotic stress tolerance-role of glycine betaine. *Current genomics*, 14(3), 157-165.
38. Sairam, R. K., & Tyagi, A. (2004). Physiology and molecular biology of salinity stress tolerance in plants. *Current science*, 407-421.
39. Chen, T. H., & Murata, N. (2002). Enhancement of tolerance of abiotic stress by metabolic engineering of betaines and other compatible solutes. *Current opinion in plant biology*, 5(3), 250-257.
40. Ryu, H., & Cho, Y. G. (2015). Plant hormones in salt stress tolerance. *Journal of Plant Biology*, 58, 147-155.
41. Fahad, S., Hussain, S., Matloob, A., Khan, F. A., Khaliq, A., Saud, S., ...& Huang, J. (2015). Phytohormones and plant responses to salinity stress: a review. *Plant growth regulation*, 75, 391-404.
42. Fahad, S., Hussain, S., Matloob, A., Khan, F. A., Khaliq, A., Saud, S., ...& Huang, J. (2015). Phytohormones and plant responses to salinity stress: a review. *Plant growth regulation*, 75, 391-404.
43. Zhu, G. Y., Kinet, J. M., Bertin, P., Bouharmont, J., & Lutt, S. (2000). Crosses between cultivars and tissue culture- selected plants for salt resistance improvement in rice, *Oryza sativa*. *Plant Breeding*, 119(6), 497-504.
44. Chinnusamy, V., Jagendorf, A., & Zhu, J. K. (2005). Understanding and improving salt tolerance in plants. *Crop science*, 45(2), 437-448.

45. Chen, T. H., & Murata, N. (2002). Enhancement of tolerance of abiotic stress by metabolic engineering of betaines and other compatible solutes. *Current opinion in plant biology*, 5(3), 250-257.
46. Chen, T. H., & Murata, N. (2002). Enhancement of tolerance of abiotic stress by metabolic engineering of betaines and other compatible solutes. *Current opinion in plant biology*, 5(3), 250-257.
47. Rahman, M. M., Hagare, D., Maheshwari, B., & Dillon, P. (2015). Impacts of prolonged drought on salt accumulation in the root zone due to recycled water irrigation. *Water, Air, & Soil Pollution*, 226, 1-18.
48. Zhang, X., Walker, R. R., Stevens, R. M., & Prior, L. D. (2002). Yield- salinity relationships of different grapevine (*Vitisvinifera* L.) scion- rootstock combinations. *Australian Journal of Grape and Wine Research*, 8(3), 150-156.
49. Bernstein, L. (1975). Effects of salinity and sodicity on plant growth. *Annual review of phytopathology*, 13(1), 295-312.
50. Gupta, S., Schillaci, M., Walker, R., Smith, P. M., Watt, M., &Roessner, U. (2021). Alleviation of salinity stress in plants by endophytic plant-fungal symbiosis: Current knowledge, perspectives and future directions. *Plant and Soil*, 461, 219-244.
51. Israel, A., Langrand, J., Fontaine, J., &Lounès-HadjSahraoui, A. (2022). Significance of arbuscularmycorrhizal fungi in mitigating abiotic environmental stress in medicinal and aromatic plants: a review. *Foods*, 11(17), 2591.
52. Bhattacharyya, P. N., &Jha, D. K. (2012). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology*, 28, 1327-1350.
53. Dojima, T., &Craker, L. E. (2016). Potential benefits of soil microorganisms on medicinal and aromatic plants. In *Medicinal and Aromatic Crops: Production, Phytochemistry, and Utilization* (pp. 75-90). American Chemical Society.
54. Karthikeyan, B., Jaleel, A.C., Azooz, M.M., 2009. Individual and Combined Effects of *Azospirillumbrasilense* and *Pseudomonas fluorescens* on Biomass Yield and Ajmalicine Production in *Catharanthusroseus*. *Academic Journal of Plant Sciences* 2, 69-73.
55. Egamberdieva, D., Jabborova, D., Mamadalieva, N., 2013. Salt-tolerant *Pseudomonas extremorientalis* able to stimulate growth of *Silybummarianum* under salt stress condition. *Medicinal and Aromatic Plant Science and Biotechnology* 7(Special Issue), in press

56. Golpayegani, A., Tilebeni, H.G., 2011. Effect of Biological Fertilizers on Biochemical and Physiological Parameters of Basil (*Ocimum basilicum* L.) Medicine Plant. *American-Eurasian Journal of Agricultural & Environmental Sciences* 11, 411–416.
57. Bharti, N., Yadav, D., Barnawal, D., Maji, D., Kalra, A., 2013. *Exiguobacterium oxidotolerans*, a halotolerant plant growth promoting rhizobacteria, improves yield and content of secondary metabolites in *Bacopa monnieri* (L.) Pennell under primary and secondary salt stress. *World*.
58. Selvaraj, T., Sumithra, P., 2011. Effect of *Glomus aggregatum* and plant growth promoting rhizomicroorganisms on growth, nutrition and content of secondary metabolites in *Glycyrrhiza glabra* L. *Indian Journal of Applied & Pure Biology* 26, 283–290.
59. Bharti, N., Barnawal, D., Awasthi, A., Yadav, A., Kalra, A., 2014. Plant growth promoting rhizobacteria alleviate salinity induced negative effects on growth, oil content and physiological status in *Mentha arvensis*. *Acta Physiologiae Plantarum* 36, 45–60.
60. Jamil, A., Riaz, S., Ashraf, M., & Foolad, M. R. (2011). Gene expression profiling of plants under salt stress. *Critical Reviews in Plant Sciences*, 30(5), 435-458.
61. Chinnusamy, V., Jagendorf, A., & Zhu, J. K. (2005). Understanding and improving salt tolerance in plants. *Crop science*, 45(2), 437-448.
62. Requena, N., Jimenez, I., Toro, M., & Barea, J. M. (1997). Interactions between plant-growth-promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi and *Rhizobium* spp. in the rhizosphere of *Anthyllus cytisoides*, a model legume for revegetation in mediterranean semi-arid ecosystems. *The New Phytologist*, 136(4), 667-677.
63. Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. *Functional Plant Biology*, 37(7), 613-620.
64. Dougherty, T. C., & Hall, A. W. (1995). *Environmental impact assessment of irrigation and drainage projects* (Vol. 53). Food & Agriculture Org.
65. Reganold, J. P., Papendick, R. I., & Parr, J. F. (1990). Sustainable agriculture. *Scientific American*, 262(6), 112-121.
66. Assaf, M., Korkmaz, A., Karaman, Ş., & Kulak, M. (2022). Effect of plant growth regulators and salt stress on secondary metabolite composition in Lamiaceae species. *South African Journal of Botany*, 144, 480-493.
67. Qin, S., Feng, W. W., Zhang, Y. J., Wang, T. T., Xiong, Y. W., & Xing, K. (2018). Diversity of bacterial microbiota of coastal halophyte *Limonium sinense* and amelioration

of salinity stress damage by symbiotic plant growth-promoting actinobacterium *Glutamicibacter halophytocola* KLBMP 5180. *Applied and Environmental Microbiology*, 84(19), e01533-18.

68. Ruijter, E., & Orru, R. V. (2013). Multicomponent reactions—opportunities for the pharmaceutical industry. *Drug Discovery Today: Technologies*, 10(1), e15-e20.

UNDER PEER REVIEW