

Improving crop resilience to salinity

stress using growth regulators

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Worldwide climate change and declining availability of high-quality water lead to an increase in the salinization of agricultural lands. One of the major abiotic factors limiting plant growth and development is soil salinity. High salts concentrations in soil and water interfere plant physiological and metabolic processes, ultimately resulting in reduced growth, quality, and yield. In recent years, the application of plant growth regulators (Exogenous application or seed priming) can enhance plant tolerance to stress by modifying ionic and redox homeostasis, enhancing antioxidant activity, and affecting stress-responsive gene expression. Growth regulators such as abscisic acid, salicylic acid, jasmonic acid, gibberellins, cytokinins, and ethylene play an important role in reducing the harmful effects of salinity on plant growth and yield.

Keywords: Abscisic acid, Cytokinins, Growth regulators, Gibberellins, Salinity, Salicylic acid

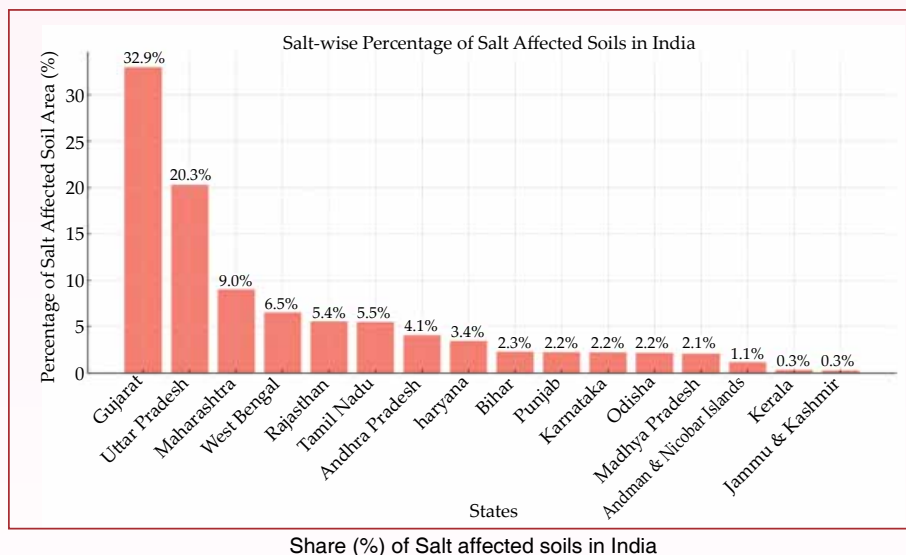
SOIL salinity is a significant abiotic factor that impacts crop plants and restricts global production. In India, around 6.73 million hectares of land are impacted by soil salinity, constituting roughly 2.1% of the nation's entire geographical area. Gujarat, Uttar Pradesh and Maharashtra shares more than 60% salt affected area on the country. Estimates indicate that approximately 10% of land becomes salinized annually, and by 2050,

about 50% of arable land would be damaged by salt. Salinization can be occurred by two ways: primary and secondary. Primary salinization happens spontaneously as a result of wind and rain-induced sea salt deposits or rock weathering. In arid regions, excessive irrigation often leads to secondary salinization, wherein salts accumulate due to inadequate drainage and poor water management, compelling farmers to leave affected farms and intensifying land degradation.

It is becoming major concern of irrigated agriculture.

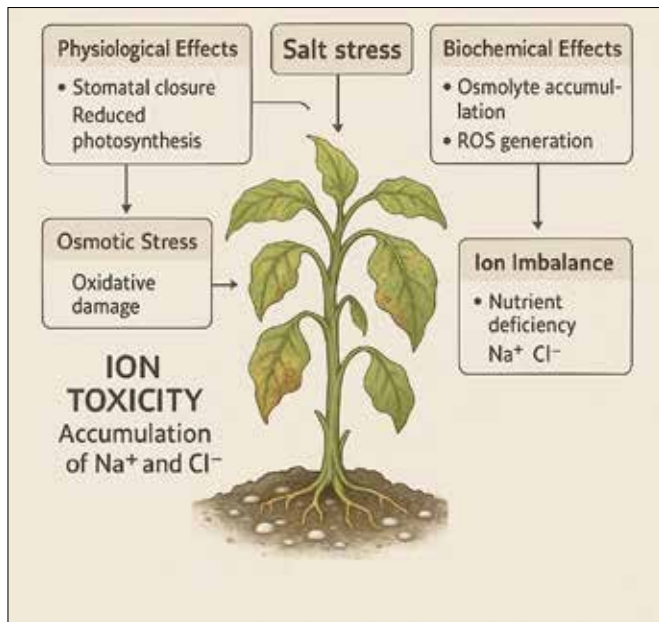
Effects of salinity stress on plants

Salt stress has detrimental effect of the plants. Salt stress resulted in physiological effects, biochemical effects, osmotic stress and ion imbalance. Due to stomatal closure, which restricts CO₂ uptake and chlorophyll breakdown during extended salt exposure, salt stress drastically alters metabolic pathways and photosynthesis. In plant tissues, hazardous levels of sodium (Na⁺) and chloride (Cl⁻) ions build up,





Stunt growth and poor germination of wheat under saline condition



Effect of salinity stress on crop plants

resulting in cellular toxicity and preventing enzymatic activity. Ion imbalance, osmotic stress, and oxidative damage are the causes of salt toxicity. Increased salinity causes an accumulation of Na^+ and Cl^- , which upsets the equilibrium of vital nutrients, especially potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). Important

functions including protein synthesis and enzyme activation are impacted by this ionic imbalance. Salt stress modifies biochemical pathways, which results in osmolyte buildup, reactive oxygen species (ROS) generation, and modifications to metabolic processes.

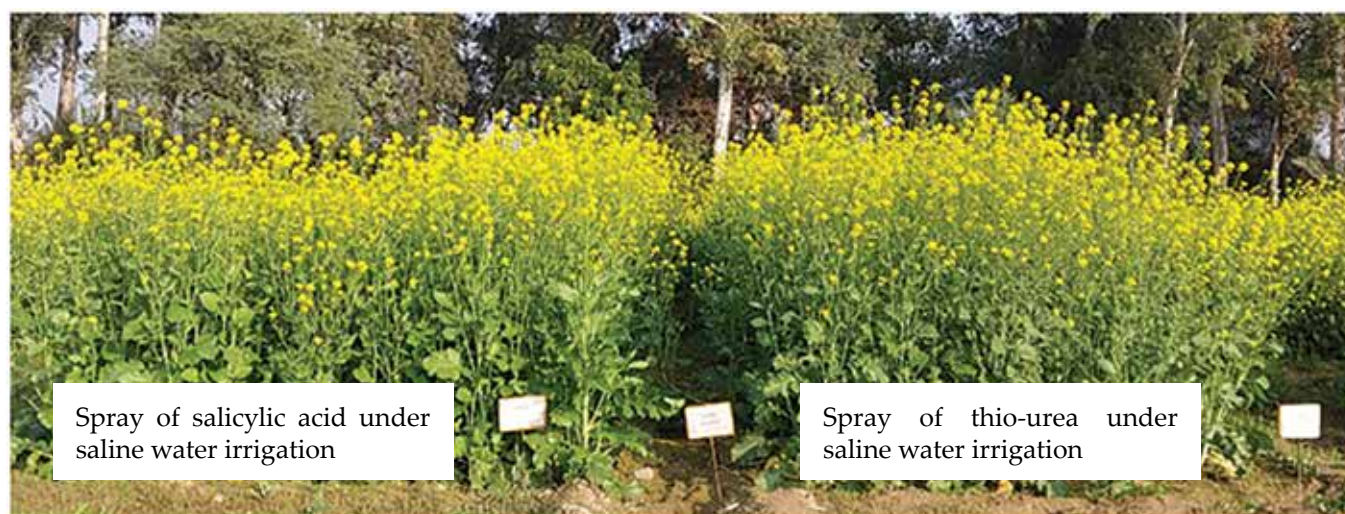
Role of specific growth regulators in mitigating salinity stress

To reduce the detrimental effects of salt stress on plant growth and yield, two distinct strategies can be adopted. The first strategy involves using molecular or traditional breeding to create cultivars that are resistant to salt. The second strategy pertains to agronomical methods and involves applying different plant growth regulators (PGRs). Synthetic or naturally occurring organic chemicals that affect higher plant biological processes at very low concentrations are known as plant growth regulators (PGRs). PGRs are widely affordable and easy to apply to crops, and they all have the same function of controlling intrinsic hormone levels in plants by modifying signaling within different hormone transduction pathways. The effectiveness of PGRs depends on the interaction of host plant with soil environment. Certain PGRs have been demonstrated to improve plants' ability to withstand salt including ethylene, salicylic acid (SA), abscisic acid (ABA), jasmonic acid (JA), and brassinosteroids (BRs).

Table 1. Roles of specific PGRs under salinity stress with examples

PGRs	Structures	Role	Example
Abscisic Acid (ABA)		<ul style="list-style-type: none"> ❖ Key stress hormone, regulates stomatal closure to reduce water loss under salinity stress, maintaining plant water status. ❖ Enhances the expression of stress-responsive genes and promotes the accumulation of osmolytes to improve osmotic adjustment. 	Improves salt tolerance in crops like wheat and maize by enhancing root growth and reducing Na^+ accumulation
Gibberellins		<ul style="list-style-type: none"> ❖ Promote cell elongation, seed germination, and overall growth ❖ Counteract growth inhibition caused by high salt levels 	Improve salt tolerance in tomato and barley by promoting shoot and root growth
Auxins (e.g., Indole-3-Acetic Acid)		<ul style="list-style-type: none"> ❖ Regulate root development, critical for water and nutrient uptake 	Mitigates salinity stress in soybean by improving root growth and reducing oxidative damage

PGRs	Structures	Role	Example
Cytokinins		❖ Delay senescence, maintain chlorophyll content, and promote cell division	Kinetin application improves salt tolerance in wheat by enhancing chlorophyll stability and antioxidant activity
Salicylic Acid (SA)		❖ Enhances plant defense against salinity-induced oxidative stress and improves photosynthetic efficiency	Salt tolerance in mung bean and rice by enhancing antioxidant capacity and maintaining membrane stability
Jasmonic Acid (JA)		❖ Enhances stress signaling and improves plant resilience to salinity by activating defense mechanisms	Methyl jasmonate application alleviates salinity stress in pepper by improving photosynthetic rates and reducing Na ⁺ toxicity
Brassinosteroids		❖ Improve plant growth and stress tolerance by enhancing photosynthetic efficiency and membrane stability	24-epibrassinolide application enhances salt tolerance in cucumber and rice by improving photosynthesis and antioxidant defenses
Ethylene		❖ Modulates stress responses, effects varying based on concentration and plant species ❖ At low levels, it can promote stress tolerance	Application of ethylene precursors (e.g. ethephon) can enhance salt tolerance in certain crops like maize by improving root growth and ion balance
Thio-urea		❖ Cope with drought, heat and heavy metal toxicity by improving antioxidant defense mechanism ❖ Potent antioxidant, scavenging harmful ROS, Protect oxidative damage	Improve grain yield by influencing gas exchange, nutrient uptake and sugar mechanism in various crops

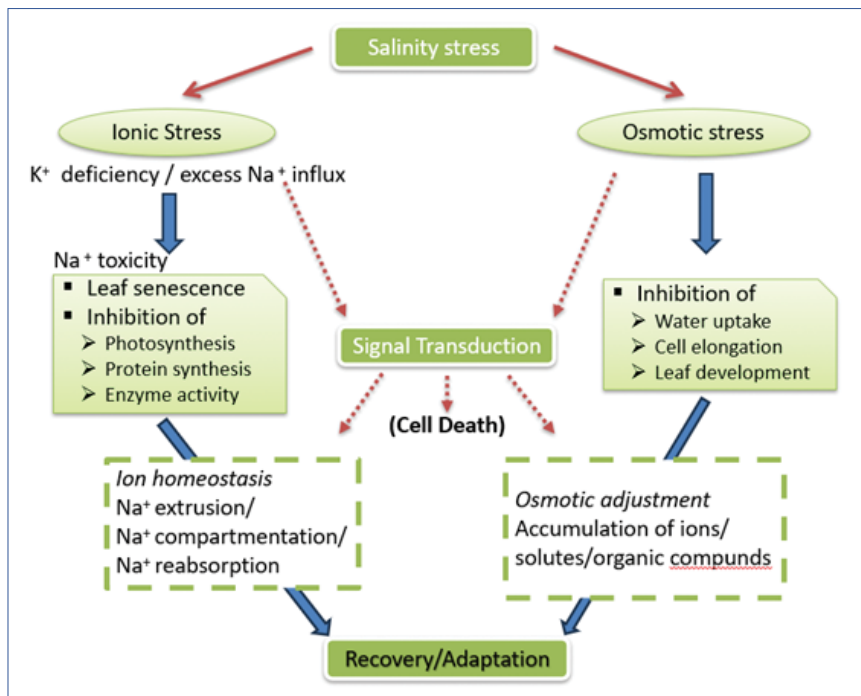


Effect of foliar spray of thio-urea and salicylic acid on the mustard crop under saline water irrigation

Mechanisms: One of the key mechanisms through which PGRs induce salt tolerance is the regulation of ion homeostasis and compartmentalization. ABA promotes selective accumulation and intracellular sequestration of Na⁺ ions in vacuoles, lessening cytoplasmic toxicity and enzyme activity. At the same time, PGRs like SA and JA enhance the accumulation of osmolytes proline, glycine betaine and soluble sugars, which account for osmotic adjustment and cell turgor maintenance. Oxidative stress, a significant salinity impact, is tempered by PGR-augmented activity of the antioxidant defense system. Exogenously applied PGRs augment the activity of some

key enzymic antioxidants like superoxide dismutase (SOD), catalase (CAT), peroxidase (POD) and ascorbate peroxidase (APX), thus scavenging reactive oxygen species (ROS) and safeguarding cellular structures from oxidative damage.

Furthermore, PGRs are also crucial for maintaining photosynthesis under salinity stress. Brassinosteroids and cytokinins have been found to preserve chloroplast ultrastructure, maintain chlorophyll content and keep photochemical activity intact, leading to enhanced carbon assimilation. The regulators also affect root architecture, with auxins and cytokinins promoting



Effect of salinity on the plant and recovery through different mechanisms

lateral root growth and augmenting the surface area of roots for water and nutrient uptake. Furthermore, ABA-mediated regulation of stomata reduces transpirational water loss, thus enhancing water-use efficiency under salt stress. Importantly, functional coordination between various PGRs enables plants to coordinate a highly integrated response to salinity. ABA, SA, JA and ethylene crosstalk regulates stress-responsive gene expression, ion transport and hormonal signaling pathways, leading to enhanced and integrated defense.

Practical approaches and application techniques

The practical application of PGRs in saline agriculture requires strategic timing, appropriate formulation and integration with complementary agronomic practices. Seed priming with low concentrations of SA, GA₃, or BRs has been shown to enhance germination, seedling vigour and stress preparedness by inducing a primed physiological state. Foliar application is a widely adopted approach, offering rapid uptake and systemic effects; multiple sprays at critical phenological stages such as tillering and flowering can effectively alleviate salt-induced damage. In salt-affected irrigated systems,

soil or fertigation-based delivery of PGRs particularly ABA analogs and polyamines enables direct targeting of the root zone, enhancing ion regulation and root metabolic activity. The efficacy of PGRs is further amplified when combined with salt-tolerant genotypes and soil amendments. For instance, integrated use of SA and halophilic plant growth-promoting rhizobacteria (PGPR) has demonstrated synergistic effects on nutrient uptake, antioxidative capacity and biomass accumulation in salt-stressed wheat.

Given the projected expansion of salt-affected arable land, especially in arid and semi-arid agro-ecosystems, the use of PGRs represents a promising strategy for enhancing crop performance under salinity stress. However, successful field-level implementation necessitates crop-specific standardization of dosages, delivery methods and timing schedules.

Advances in nano-formulation technologies offer new avenues for improving the stability, bioavailability and targeted delivery of PGRs. Future research should focus on elucidating the molecular networks underpinning PGR-mediated salinity tolerance and on integrating these compounds with genomics-assisted breeding, microbial bio stimulants and precision agriculture tools to develop resilient and sustainable crop production systems for salt-affected regions.

SUMMARY

High salts concentrations in soil and water interfere plant physiological and metabolic processes, ultimately resulting in reduced growth, quality, and yield. The application of plant growth regulators is a key strategy for enhancing crop tolerance to salinity stress. These regulators help plant survival and productivity under salt-affected conditions by regulating hormonal signaling, increasing antioxidant activity, and maintaining ionic and osmotic balance.

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