



**Biotica
Research
Today**

Vol 2:11 **1211**
2020 **1214**

Salt Stress Injury and Resistance Mechanism in Plants

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 **Open Access**

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Keywords

Mitigation of salt stress, Oxidative stress, Salt stress effects, Salt tolerance

Article History

Received in 17th October 2020

Received in revised form 28th November 2020

Accepted in final form 29th November 2020

E-mail: bioticapublications@gmail.com

How to cite this article?

Alagappan, 2020. Salt Stress Injury and Resistance Mechanism in Plants. Biotica Research Today 2(11): 1211-1214.

Abstract

Salinity is a major abiotic stress limiting growth and productivity of plants in many areas of the world due to increasing use of poor quality of water for irrigation and soil salinization. Plant adaptation or tolerance to salinity stress involves complex physiological traits, metabolic pathways, and molecular or gene networks. A comprehensive understanding on how plants respond to salinity stress at different levels and an integrated approach of combining molecular tools with physiological and biochemical techniques are imperative for the development of salt-tolerant varieties of plants in salt-affected areas. Recent research has identified various adaptive responses to salinity stress at molecular, cellular, metabolic, and physiological levels, although mechanisms underlying salinity tolerance are far from being completely understood.

Introduction

The term, 'salt-injury' refers to soils with substantial enough salt concentrations to affect mainly plant health, and subsequently affects soil properties, water quality and other land and soil resource uses. Salt-affected areas generally occur in semi-arid and arid climates where precipitation is not adequate to leach salts, causing them to remain in the soil profile. Salinization, the process of salt accumulation, most often occurs where surrounding soil or underlying parent material contains high levels of soluble minerals, where drainage through the soil is poor, where water ponds and evaporates, or where shallow water tables allow salty groundwater to move upward and deposit salts due to evaporation.

Development of Salt-Affected Soils

A salt is a water-soluble compound that, in soil, may include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), bicarbonate (HCO_3^-), or sulfate (SO_4^{2-}). For example, Ca^{2+} and SO_4^{2-} form to make the salt gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Salts in soil can develop from the weathering of primary minerals or be deposited by wind or water that carries salts from other locations. Salt-affected areas generally occur in semi-arid and arid climates where precipitation is not adequate to leach salts, causing them to remain in the soil profile. Salinization, the process of salt accumulation, most often occurs where surrounding soil or underlying parent material contains high levels of soluble minerals, where drainage through the soil is poor, where water ponds and evaporates, or where shallow water tables allow salty groundwater to move upward and deposit salts due to evaporation. James *et al.*, (2011) reported that the Major genes for Na^+ exclusion, *Nax1* and *Nax2* (wheat HKT1;4 and HKT1;5), decrease Na^+ accumulation in bread wheat leaves

under saline and waterlogged conditions.

Effect of Salt Stress on Crop Growth and Development

Germination

Seed germination in saline condition is affected by three ways. Increased osmotic pressure of the soil solution which restricts the absorption and entry of water into the seeds. Certain salt constituents are toxic to the embryo and seedlings. Anions like CO_3 , NO_3 , Cl^- , SO_4 are more harmful to seed germination. Salt stress hampers the metabolism of stored materials. Protease, enzyme catalyses the solubility of proteins to soluble nitrogen in seeds is inhibited by salinity. Alfa - amylase activity is very much inhibited. Therefore starch to sugar conversion is prevented. Salinity delays the synthesis of nucleic acids and RNAase. Salinity exerts an inhibition of glyoxysomal catalase, malate synthase and isocitrate lyase leads to reduction of glycerides and more of free fatty acids in oil seeds and the mechanism of salinity tolerance were reported by Munns and Tester (2008).

Vegetative Growth

Due to accumulation of more ions in the soil as well as in the root zone, plants are unable to absorb water and thus water deficit stress condition is occurred in plants, which is termed as physiological drought. During vegetative stage, salt induced water stress causes closure of stomata leads to reduction in CO_2 assimilation and transpiration. Reduced turgor potential affects the leaf expansion. Because of reduction in leaf area, light interception is reduced, photosynthetic rate is affected which coupled with spurt in respiration, resulting into reduced biomass accumulation.

Photosynthetic

Accumulation of high concentration of Na^{2+} and Cl^- in chloroplast, photosynthesis is inhibited. Since photosynthetic electron transport appears relatively insensitive to salts, either carbon metabolism or photo phosphorylation may be affected. Photosynthetic enzyme or the enzymes responsible for carbon assimilation are very sensitive to the presence of NaCl.

Reproductive Growth and Yield

Under salt stress condition, the onset of flowering is delayed due to the limitations of source size. The quantum of reproductive structure such as number of flowers/ panicle is very much reduced. Due to high deposition of salts in tissues, most of the metabolic processes such as synthesis of proteins, amino acids, sugars, starch and other organic compounds are altered. This disturbance in the normal metabolism affects the mobility of metabolites from the site of production to the site of utilization for reproductive growth. Therefore the development of reproductive structures and

further maturation processes are very much affected which ultimately diminish the crop yield. Due to imbalance of nutrients under salt stress, hormone synthesis is hampered leads to reduction in quantity as well as quality of crop produce. Rahnema *et al.*, (2010) reported that the stomatal conductance as a screen for osmotic stress tolerance in durum wheat growing in saline soil.

Crop Adaptations to Salt Stress

Based on the responses to high concentration of salts, plants can be divided into two broad groups, viz., (i) Halophytes, and (ii) Glycophytes.

Halophyte

Group of plants able to grow even in high saline conditions, which are otherwise called as salt tolerant types. They are native to saline soils.

Glycophytes (Literally "sweet plants") Nonhalophytes

They are sensitive plants and unable to grow under saline conditions. Most of the cultivated crop species belong to glycophytes. Glycophytes begin to show the signs of growth inhibition, leaf discoloration and loss of dry weight, when concentration of the salts reaches above the threshold level. Among the crops, maize, onion, citric lettuce and bean are highly sensitive to salt. Cotton and barley are moderately sensitive sugar beet and date palms are highly tolerant.

Mechanism of Salt Tolerance

Avoidance

Avoidance is the process of keeping the salt ions away from the parts of the plant where they are harmful.

- Salt Exclusion
- Salt Extrusion
- Salt Dilution
- Compartmentation of ions

Tolerance

Osmotic adjustment Hormone synthesis - ABA stress hormone, hardens plants against excess salts.

Salt Exclusion

The ability to exclude salts occurs through filtration at the surface of the root. Root membranes prevent salt from entering while allowing the water to pass through. The red mangrove is an example of a salt-excluding species.

Salt Excretion/ Extrusion

Salt excreters remove salt through glands or bladders or cuticle located on each leaf. Salt bladders - eg. *Atriplex*, *Mesembryanthemum crystallinum* L. Salt glands - active process, selective for sodium and chloride (eg) Black and white mangroves Secretion through cuticle – eg) *Tamarix* Salt glands-

dump sites for the excess salt absorbed in water from the soil; help plants adapt to life in saline environments.

Salt Dilution

By dilution of ions in the tissue of the plant by maintaining succulence. Plants achieve this by increasing their storage volume by developing thick, fleshy, succulent structures. Succulence is mainly a result of vacuoles of mesophyll cells filling with water and increasing in size. This mechanism is limited by the dilution capacity of plant tissues.

Compartmentation of Ions

Organ level - high salts only in roots compared to shoots especially leaves. At cellular level- high salts in vacuoles than cytoplasm thus protecting enzymes.

Salt Tolerance in Crop Plants

Salt Tolerance of Cereal Crops

Most of the major cereal crops exhibit high tolerance to soil salinity. In this group are sorghum, wheat, triticale, rice, oats and barley. Only exceptions are corn and rice. All cereals tend to follow the same sensitivity or tolerance pattern in relation to their stage of growth. Seeding or early vegetative stage appears to be the most sensitive. The phenomenon has been reported for sorghum, wheat, barley, corn and rice. Salt stress can have a significant effect on the developmental process.

Mitigation of Salt Stress

- Seed hardening with NaCl (10 mM concentration)
- Application of gypsum @ 50% Gypsum Requirement (GR)
- Incorporation of daincha (6.25 t/ha) in soil before planting
- Foliar spray of 0.5 ppm brassinolide for increasing photosynthetic activity
- Foliar spray of 2% DAP + 1% KCl (MOP) during critical stages
- Spray of 100 ppm salicylic acid
- Spray of 40 ppm of NAA for arresting pre-mature fall of flowers/ buds/ fruits
- Extra dose of nitrogen (25%) in excess of the recommended
- Split application of N and K fertilizers
- Seed treatment + soil application + foliar spray of Pink Pigmented Facultative Methanotrophs (PPFM) @ 10⁶ as a source of cytokines

The factors that determine the accumulation of salt in a soil are as follows:

- Source of salt (local weathering, surface and subsurface waters, human activities);
- Transporting agents accumulating salts from large areas to smaller deposits as well as from thick geological strata to thinner horizons (usually water, wind);
- Limited vertical or horizontal drainage conditions;

- Driving force for movement of solution, usually relief (surface runoff),
- Hydraulic gradient (groundwater flow), suction (capillary transport) or concentration gradient (diffusion);
- Negative water balance (evapo-transpiration greater than precipitation).
- Continental salt accumulation due to intense weathering and arid climate or due to hydro-geological conditions (e.g. closed evaporative basins).

Major Categories of Salt Affected Soils

- **Saline soil (Solonchak)** with high amount of water soluble salts.
- **Alkaline soil (Solonetz)**, high alkalinity and high Exchangeable Sodium Percentage (ESP).
- **Magnesium soil:** high magnesium content in the soil solution.
- **Gypsiferous soil:** strong gypsum or calcium sulphate (CaSO₄) accumulation.
- **Acid sulphate soil:** highly acidic iron or aluminium sulphate accumulation.
- **Black Alkali soils:** contains high amounts of carbonates and bicarbonates of Sodium.
- **White Alkali soils:** contains high amount of chlorides and sulphates of Sodium.

Oxidative Stress Mechanism: Green cells in plants functioning in aerobic environment are subjected to continuous threat from oxygen which due to partial reduction forms Toxic Reactive Oxygen Species (TROS) or Reactive Oxygen Species (ROS) like superoxide (O₂⁻), hydrogen peroxide (H₂O₂) and hydroxyl radicals (OH) etc. ROS degrades proteins, lipids, nucleic acids and distort biological membrane. Plants have both enzymic and non enzymic antioxidants to fight against toxic oxygen species and protect them from oxidative stress. The best antioxidant produced by plant against ROS is ABA (salt affected situation).

Classification of salt tolerance crops:

- **Salt sensitive crops:** Examples: Maize, Onion, Citric Lettuce and Beans.
- **Moderately Sensitive Crops:** Examples: Cotton and Barley.
- **Highly salt tolerant crops:** Examples: Sugar beet and Date palms.

Conclusion

By adopting above soil amendments we can restore soil health and structure vegetation, Recreate ecological function of soils, Decrease bioavailability of toxic pollutants, Decrease erosion and improve soil drainage, Reduce costs compared to traditional remediation

techniques and may abate acid mine drainage. and the main Threats to Indian agriculture in future is due to the Invasive Alien Species, Abiotic Stresses, Biotic Stresses, Market factors, Climate Change, Constraints in the exchange of genetic resources, Intellectual Property Rights (IPR) and access to technologies, Diminishing support to public on good research and Increasing population (By 2030 India will be World No.1) crossing the level of 130 crores.

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