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SALINITY CONSTRAINTS AND AMELIORATION IN PLANTS

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Abstract: Salinity in soil is one of the major constraints of crop production in coastal area and upland agricultural land. Some plants have internal mechanism to avoid or tolerate salinity upto certain extent whether some are very sensitive. On the basis of their tolerance they are divided into glycophyte (sensitive to salt) and halophyte (insensitive to salt). Most of the crops are intolerant of one third of salt present in sea water while some have develop mechanism for counteract the effects of salinity. The mechanisms of salinity amelioration in plant are synthesis of osmoprotectants; exclusion of salt and compartmentalization of salt thereby maintain hydration in the cell. The genetic component involved in exclusion of Na^+ into the root and loading into the xylem vessel for long-distance transport out of the root is Salt Overly Sensitive (SOS) signaling pathway which has three components: SOS1, SOS2 and SOS3. The SOS3 sense salinity signal through Ca ions and interacts with SOS2 which activate SOS1 by phophorylation for transport of Na+ into growing region. Thus, activation of these mechanisms protects plant from adverse effects of salinity.
Keywords: salinity, plants, SOS, osmolytes, transporters

Introduction

Soil salinity is major constraint in production of crops which affected the most of the agricultural land in the world. The productivity of soil decline due to presence of excess salt mainly chloride and sulfate of sodium (Na^+), calcium (Ca^+) and Magnesium (Mg^+) which result in diminishing of exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), electrical conductivity (EC_e), soil reaction (pHs), etc. and when excess ions accumulate in the rhizosphere, the physical, chemical and biological properties of soil deteriorate, and adversely affect the economic yield of the crops (Stavi et al., 2021). Saline soil characterized on the basis EC_e parameter in which EC_e greater than 4 dS m^{-1} in soil make it unsuitable for cultivation of staple crops while sodic soil characterized by ESP in which ESP greater than 15 render them unsuitable for cultivation of most of the crops (Bryla et al., 2021). Among three salts Na salts on plants were reported to be more harmful than the others. As the accumulation of salt concentration in soil increase the EC_e parameter increase accordingly, hence this value determined the degree of soil salinity. The formation of sodic soil induced by groundwater containing carbonates and bicarbonates, desalinization, the

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reduction of sulphate ions under anaerobic conditions and alternate wet and dry seasons. These factors favors the soil exchange complex with simultaneous increase in pH results in excess exchangeable sodium ion and high pH that adversely affects physical properties and water permeability of soil (Flowers et al. 2020).

Table 1: Type of soil affected by salt

Soil type	Soil EC (dS m^{-1})	Soil pH	Soil ESP	Soil SAR
Saline	>4	<8.5	<15	<13
Sodic	variable	>8.5	>15	>13
Saline-Sodic	>4	>8.5	variable	>13

Mechanisms of salt tolerance in plants

There are two mechanism of salinity amelioration in plants- 1. Avoidance and 2. Tolerance. The plants avoid salt in four ways- 1. Salt Exclusion, 2. Salt Extrusion, 3. Salt Dilution and 4. Compartmentation of ions into the vacuole whereas tolerate salinity by osmotic adjustment and synthesis of antistress hormone ABA. In exclusion process salt exclude at the surface of roots during uptake while in extrusion process salt removed through salt gland and salt bladder. Salt dilution occurs through increasing storage volume in the tissues by developing thick, fleshy and succulent structures (Huang et al., 2021). Ionic imbalance in the soil affects solute potential as well as the total water potential. Solute potential decrease as the accumulation of ions increase in the soil water results in lower the solute potential and thereby the total water potential of the soil. Excess Na^+ ion competes with K^+ and inhibits its absorption and affects the water uptake and turgor in the leaves. The ion homeostasis particularly potassium-to-sodium ratio determine the salinity effects on cellular functions. The ratio of potassium-to-sodium determines the level of salinity tolerance in plants (Cherel and Gillard, 2019). Salt tolerant trait might be determined by the higher value of potassium-to-sodium in plant and soil. The internal water potential of the plant must be lower than that of the soil water for uptake of water from rhizosphere. The osmotic adjustment is the way for keeping lower water potential in cell for maintain of gradient of water potential between plant and soil. Organic acids, sugars (sucrose and fructans), polyol (trehalose) and amino acids *viz.* proline, glycine betaine, etc. are the osmolytes which mediate the osmotic adjustment by keeping the water molecule bind in their structure (Eva van et al., 2020). Hence, the high concentrations of these osmolytes in the cell save the plant under salinity stress. There are three mechanisms to prevent the accumulation of Na^+ in the cytoplasm *viz.* suppress influx, activate efflux and compartmentalize in the vacuole. Salt compartmentalization in the vacuole need energy and two types of pumps acting there viz. H^+-ATPase (V-ATPase) and H^+-PPase (V-PPase-Pyrophophatase). Some salts also move through transpirational stream to xylem parenchyma/older tissues (Wu et al., 2023).

Na^+ ⇨ GIPC ⇨ CNGC ⇨ Ca^{2+} signaling pathways ⇨ SOS3 ⇨ SOS2 ⇨ SOS1 ⇨ activation of Na^+/H^+ antitransporter ⇨ efflux of Na^+

Fig.1 Activation of Na^+/H^+ antitransporter through Ca^{2+} and SOS

The antiport and symport transporter *viz.* Na^+ transporter -AtHKT1:1, Na^+/H^+ antiporter-AtNHX1, K^+/Na^+ symporter TaHKT1, and Na+/H+ antiporter acts in reducing the Na+ by the action of SOS. SOS1 actively involved in transport of excess Na^+ from the cytoplasm. It regulates the exclusion of Na^+ out of the root and loading into the xylem vessel for long-distance transport (Ali et al., 2021). The activation of SOS1 occurs through protein kinase activity of SOS2 which phosphorylate SOS1 for triggering the Na^+/H^+ antitransporter (Giridhar et al., 2022). The salinity stress signal transduction mediated through secondary messenger Ca^{2+} binding protein. This protein encoded by SOS3 gene which expressed after getting the salinity. The interaction of SOS gene products initiated by Ca^{2+} signaling pathway induced by salt stress. The receptor (glycosyl inositol phosphoryl ceramides-GIPC) of Na+ present on plasma membrane, induce the Ca^{2+} channel (cyclic nucleotide gated Ca2+ channel-CNGC) this leds to activation of Ca^{2+} signaling pathways (Jiang et al., 2019). SOS2/SOS3 complex form to phosphorylate SOS1 by interaction of SOS3 with SOS2 upon sensing Ca^{2+} in the cell results in efflux of Na^+ and influx of H^+ by Na^+/H^+ antitransporter. SOS2 negatively regulated by 14-3-3 proteins but inhibitory effect of this protein is minimized by Ca^{2+} binding protein kinase 5 (PKS5). The balance of Na^+/Ca^{2+} in the cell is maintain by two-pore channel 1 (TPC1), located on the vacuolar membrane, while balance between Na+/K+ ratio maintain by two-pore K+ channel 1(TPK1) after its Phosphorylation by kinase activity of Ca^{2+}- calcium-dependent protein kinase 3 (CPK3) present on the vacuolar membrane. (Yang et al., 2019). Hence, the synthesis of osmolytes and activation of SOS gene, and ion channels results in reduction of negative effects of salinity.

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