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Effects, tolerance mechanism and mitigation approaches of salt stress in Maize (*Zea mays* L.): A review

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Abstract

Salinity is one of the major abiotic stresses for crop productivity across the globe. Soil salinity has a dual impact on plants: osmotic and ionic effect. Maize is the third most important cereal crop of the world that is helping out to meet the food requirements of the world. Higher osmotic stress and ionic toxicity cause oxidative stress as well as nutritional imbalances in maize that has effects on germination rate, plant height, root growth, biomass yield, pollen grain viability and yield of maize crop. In response to salinity, maize have evolved resistance mechanisms including ionic balance maintenance, osmoregulation, stomatal conductance regulation and phytohormonal regulation. The ionic balance is maintained by increasing the K+ ions and decreasing Na+ in cytosol. The osmoregulation takes place by increasing inorganic and organic compounds. The stomatal conductance regulated by production of abscisic acid. The production of jasmonate, ABA, oxidative enzymes, spermidine and polyamine are also involved to tolerate salt stress. This stress is also being mitigated by using approaches such as soil reclamation, seed priming, exogenous application of plant growth regulators and molecular & genetic breeding techniques. The present review highlights the impact of salt stress on morphological, physiological and biochemical responses, resistance mechanisms of maize and various approaches to mitigate the effects of salt stress for its improved productivity.

Keywords: Maize, Molecular and genetic breeding, Osmoregulation, Physiological and biochemical, Seed priming, Soil salinity

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Introduction

Climate change, depleted water resources and soil salinization are the major challenges for agriculture as well as to feed the ever-growing population of the world. The saline soil is characterized with electrical conductivity of more than 4 dS m^{-1}, PH less than 8.5, Sodium adsorption ratio less than 13 and exchangeable sodium percentage of less than 15% at 25°C (Shrivastava & Kumar, 2015). Poor soil drainage, excess use of organic manure, improper irrigation practices and use of highly saline irrigation water are major causes of salinity (Sharma et al., 2016). Worldwide 20% of total cultivated land and 33% of irrigated land is affected by soil salinity and this ratio is being increased by 10% annually. It has been estimated that by the year 2050 more than 50% of irrigated land will be salinized (Jamil et al., 2011).

Maize is the third most important cereal crop of the world after wheat and rice. In the present situation of increased population, there is a need to increase production of the maize crop as it is not only used as a food source but also for many other purposes (Budakli et al., 2010). Salinity has binary effects on plants; one is osmotic stress and other one is ionic toxicity. Osmotic stress is conferred by lower water potential of soil while ionic toxicity is due to higher uptake and accumulation of ions in plants (Sheldon et al., 2017). Higher osmotic stress and ionic toxicity leads to increased oxidative stress that ultimately affects morphological parameters like germination rate, crop growth rate, yield, plant biomass and reproductive growth (Evelin et al., 2019). According to Biphasic model for maize crop, developed by Fortmeier and Schubert, during first phase of maize growth adverse effect of ion toxicity are limited to a smaller extent (Farooq et al., 2015a).

Salt tolerance is the ability of plants to withstand the harmful effects of soil salinity. Plants adopt a wide variety of mechanisms at organ, tissue, cellular and subcellular level to cope up with salt stress (Jaafer et al., 2012). Maize plants undergo immense type of modifications such as regulation of stomatal opening and closing, activation of antioxidant mechanism, osmoregulation, water content maintenance and toxic ion exclusion mechanism to overcome hazardous impacts of salt stress (Iqbal et al., 2020). Large numbers of management strategies have been developed to ameliorate salt tolerance in maize crop. One of them is the production of salt tolerant genotypes by genetic breeding and molecular techniques (Alkharabsheh et al., 2021). Other ones are exogenous application of some plant growth regulators like plant growth hormones, inorganic soil fertilizers and plant growth promoting rhizobacterium (Roy & Chowdhury, 2020).

Owing to the present situation of increased demand of food production and reduced maize crop production by salinity there was need of a comprehensive review summarizing the morpho-physio-biochemical responses of maize and mitigation approaches to cope up salinity. This will help to devise further techniques and approaches for improving salt tolerance in maize crop.

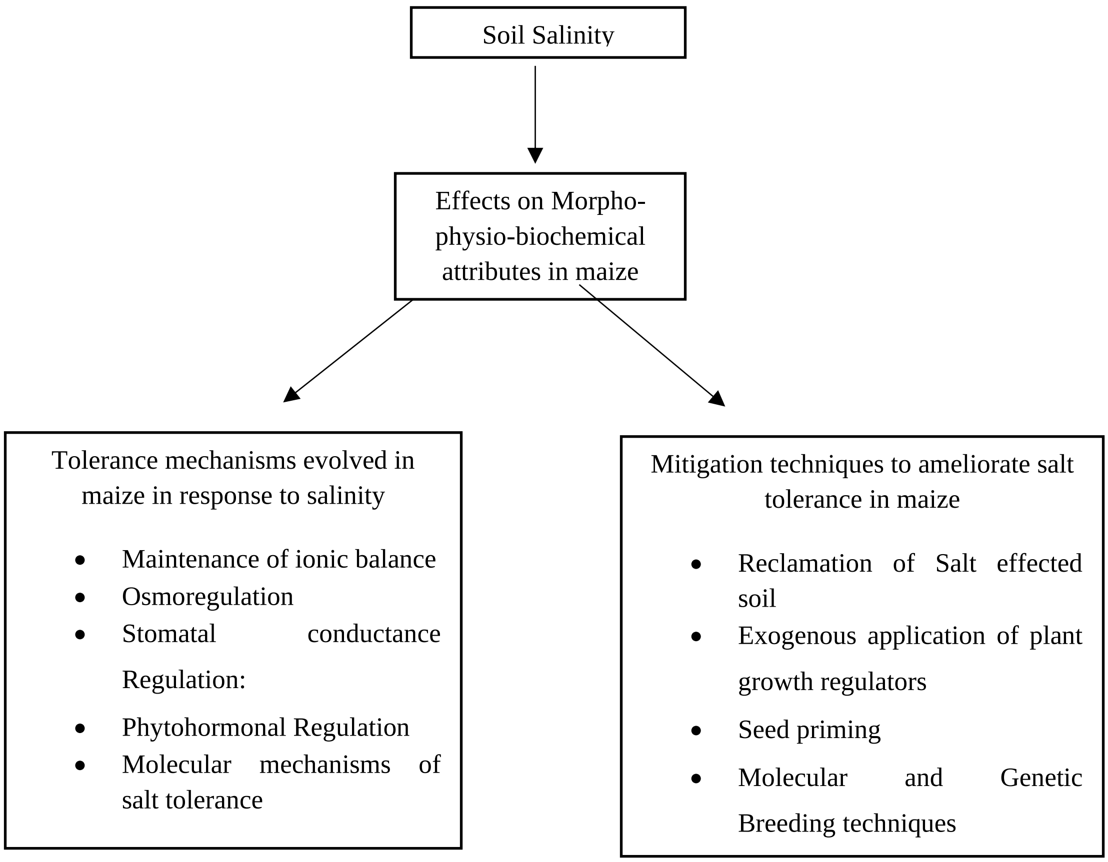

Fig. 1 Flow chart for effects, tolerance mechanisms and mitigation approaches of salt stress in maize

Effects of salt stress on maize crop

Maize is called a moderately salt sensitive crop but still it shows some morphological, physiological and biochemical responses to salinity. Salt stress also has an impact on growth and yield of maize.

Impacts on morphological attributes

Effect of soil salinity on plant growth varies with the level of salinity and phase of plant growth. Exposure of crops to salinity for a shorter period of time causes only osmotic stress but not the ionic toxicity. Long term exposure is required to cause lower water contents, ionic imbalance and oxidative stress (Farooq et al., 2015a). A comprehensive information showing the morphological parameter and how it is affected by salinity is shown in Table 1. The initial step of plant growth is the germination stage, which is the most important and sensitive stage. It is the most commonly affected trait of crops that is affected by the salt stress. This is because imbibition of water by seeds are important for seed germination and that is inhibited by the osmotic stress and sodium ions toxicity (Ahmed et al., 2017). They have also reported that NaCl concentration higher than 80mM has adverse effects on the germination rate, germination energy and germination percentage. According to (Khodarahmpour et al., 2012), mean germination time, germination rate and germination vigor index were decreased for all the varieties of maize including hybrids as compared to control.

Seedling is the most affected stage after germination. Morphological traits of maize seedlings like shoot length, root length, fresh weight, dry weight and leaf area index are greatly reduced under salt stress. Shoot length in plants is decreased due to inhibition of leaf initiation, reduction in leaf area expansion and suppression of internode length (Qu et al., 2012). This reduction in shoot length is attributed to osmotic stress. As maize is a moderately salt sensitive crop so in the first phase of soil salinity shoot length is the most commonly affected trait after seed germination. Maize plants show reduction in shoot growth even without showing signs of ion toxicity and having dark green leaves (Hassan et al., 2018). Akram et al. (2010a reported the reduction in shoot length of various maize varieties owning to increased salt stress including Pioneer 3062, Pioneer 32B33, Pioneer 30Y87, Pioneer 31R88, Dekalb 919, Dekalb 979, Dekalb 922, Hycorn 984, Hycorn 11 plus and Hycorn 993.

As the first organ of a plant that makes contact with soil are the roots of plants so they should show higher effects of soil salinity but interestingly it is observed that roots show less salt stress than shoots of plants. Roots have higher water uptake efficiency and less ions accumulated there. More ever in plants growing in saline condition casparian strips are developed near root tips. Hypodermis and endodermis of roots are suberized to prevent water loss (Zahra et al., 2020). Root growth is decreased in salt-stressed maize plants but not to greater extent due to the movement of more ions toward the upper portion of plants and prevention of water loss from roots (Soares et al., 2018).

Fresh and dry biomass of plants is reduced by the salinity due to ionic toxicity and oxidative stress. Due to lower water content, photosynthetic activity, stomatal opening & closing and metabolic activities of plants are changed that lowers the fresh and dry biomass of plants growing in saline conditions (Gong et al., 2011). (Egamberdieva et al., 2019) reported that in various maize varieties fresh and dry biomass of shoot is reduced more than that of roots. Results of (Motos et al., 2017) showed that shoot and root dry biomass is negatively related with salt stress i.e., it decreases with increased concentration of salt stress. Very little research has been done on effects of soil salinity on reproductive growth of maize plants but research on other crops like wheat show that salt stress increases sterility of plants by causing unviability of pollen (Tareq et al., 2011). No of kernels, 100-gram grain weight, no of grains per kernel and grain yield is negatively affected by salt stress due to impairment in reproductive growth of plants. The overall yield of maize crop is adversely downregulated by the hazardous impacts of soil salinity (Li et al., 2019).

Table 1 Impact on morphological attributes of maize crop

Morphological Parameters	Impact of the salinity	References
Germination rate	Germination rate decrease	(Ahmed et al., 2017); (Khodarahmpour et al., 2012)
Shoot growth	Shoot growth decrease	(Qu et al., 2012); (Hassan et al., 2018); (Akram et al., 2010a)
Root growth	Root growth decrease but not as much as shoot growth	(Zahra et al., 2020); (Soares et al., 2018)
Fresh and dry biomass	Fresh and dry biomass decrease	(Gong et al., 2011); (Egamberdieva et al., 2019); (Murat et al., 2009)
Reproductive growth	Reproductive growth decreases due to unviability of pollen grains	(Tareq et al., 2011)
Yield	Yield of crop is downregulated by salinity	(Li et al., 2019)

Impacts on physiological attributes

Soil salinity affects the growth and yield of crops and also causes impairments in morphological traits. This harm to morphological traits is attributed to certain physiological and biochemical modification as a result of salt stress. Some of the most affected physiological traits are listed in Table 2. Osmotic stress, nutritional imbalances, oxidative stress, reduction in chlorophyll content, carotenoid content, photosynthesis rate, carbon fixation and reduced relative water content are basic physiological traits affected by salinity (Hussain et al., 2017). Ionic toxicity is one of the major responses of crops towards the soil salinity because uptake of sodium ions is higher in the salt affected crops and more sodium ions are accumulated in the cell. This high amount of $Na+$ in the cell interferes with uptake of potassium, calcium, magnesium, phosphorus, nitrogen, copper, iron and zinc ions (Lee et al., 2013). In maize crop, the major interfering ion with other physiological processes and uptake of ions is sodium ion. Chloride has not much effect on the ionic toxicity in maize. It was found that uptake of potassium ions was reduced by 64 % as a result of sodium ion accumulation (Muhammad et al., 2012).

Not only potassium ions but calcium ion uptake is also reduced due to high concentration of sodium ions. During the first phase of salt stress Sodium/Calcium ratio is affected and calcium uptake is impaired. A proper concentration of calcium is required for regulation of many important functions in cells like control of cell cycle, intracellular and extracellular transport and in cell wall acidification. This response of plant to salt stress results in reduced leaf growth and expansion of leaf area (Farooq et al., 2015b). Results of (Akram et al., 2010b) showed that leaves of plants growing in saline condition have higher concentration of sodium ions while the concentration of potassium and calcium ions is greatly reduced in leaf samples.

Ionic toxicity in plants also causes osmotic stress for plants as osmotic potential of cells is reduced by the ion accumulation in cell sap. So, water starts moving out of the cell and many metabolic functions of the cell are affected. Overall osmotic potential of plants is also reduced, resulting in leaves wilting, reduction in shoot length, root length and plant's fresh biomass

(Ma et al., 2020). Both ionic toxicity and osmotic stress decrease the rate of photosynthesis and carbon dioxide assimilation rate is reduced. Light is being continuously absorbed by the plants but it is not being used in photosynthetic activities so it causes the higher production of reactive oxygen species (Khan et al., 2019). One of the key responses of plants to salt stress and lower water content is the reduction in opening and closing of stomatal aperture (Saradadevi et al., 2017). The main function of stomata is to control entry of carbon dioxide and rate of transpiration so rate of photosynthesis is adversely affected. Due to change in leaf biochemistry, membrane permeability and shrinkage in leaves movement of carbon dioxide is also reduced through mesophyll cells (Ma et al., 2020).

Table 2 Impact on physiological attributes of maize crop

Physiological parameters	Impact of the salinity	References
Ionic Imbalance	Sodium ions uptake is increased while other ions like potassium, magnesium and calcium ions uptake is decreased.	(Lee et al., 2013); (Muhammad et al., 2012); (Akram et al., 2010a)
Osmotic stress	Osmotic stress is increased	(Ma et al., 2020)
Nutritional imbalance	Salinity causes nutritional imbalances in plants	(Farooq et al., 2015b)
Photosynthetic rate	Rate of photosynthesis is decreased	(Khan et al., 2019).
Opening & closing of stomata	Opening and closing of stomata is decreased	(Saradadevi et al., 2017); (Ma et al., 2020)

Impact on biochemical attributes

Biochemical attributes of plants are greatly affected by salinity. Some of the attributes are presented in Table 3. The biochemical attributes of plants like chlorophyll a, b and carotenoids are negatively linked with salt stress. Net photosynthetic rate in maize crop is associated with these pigments and reduction of these pigments result in reduced photosynthesis. Photon yield of Photosystem II and maximum quantum is reduced in response to salt stress (Qu et al., 2012). Sodium ion accumulation affects the bioenergetic processes of photosynthesis and this effect is further elevated by the potassium deficiency. Salt stress results in decrease of chlorophyll and carotenoid content, photochemical and non-photochemical content of photosystem II, quantum yield of photosystem II and electron transport rate of photosystem I and II. In maize, the light reaction pathway of photosystem II is more affected than photosystem I (Dogru, 2021).

Proline content, polyphenol content and total sugar content are increased in the maize crop growing under saline stress but this is an adaptation of plant to combat with salt stress and to overcome osmotic stress that is produced as a result of ion accumulation (Sinay & Karuwal, 2014). Antioxidant enzyme activities are decreased in salt stressed plants that results in destructive ROS. ROS harms the bimolecular structures like lipids, proteins, nucleic acids and causes their oxidation (Khan et al., 2018). So, a major biochemical change that harms the plants under salt stress is the decrease of photosynthetic components that lowers the rate of photosynthesis. This attribute further affects morphological traits of plants and lowers its yield.

Table 3 Impact on Biochemical attributes of maize crop

Biochemical parameters	Impact of the salinity	References
Chlorophyll content	Chlorophyll a, b and carotenoid contents are decreased	(Qu et al., 2012)
Photosystem I & Photosystem II	Photochemical and non-photochemical content of photosystem II, quantum yield of photosystem II and electron transport rate of photosystem I and II is affected by salinity.	(Dogru, 2021)
Proline and total sugar content	Proline and total sugar contents are increased.	(Sinay & Karuwal, 2014)
ROS	Reactive oxygen species are increased by salinity.	(Khan et al., 2018)

Tolerance mechanisms in Maize

Plants growing in saline condition adopt themselves naturally according to the environment in order to survive. As maize is moderately salt sensitive so it adopts a variety of mechanisms to sustain through the stress. Some of these mechanisms are listed in Table 4.

Table 4 Tolerance mechanisms of maize crop

Resistance mechanism	Mechanism	Result	References
Maintenance of osmotic balance	By accumulation of K+ ions inside the cell and by transporting extra sodium ions to vacuoles from cytosol	Nutritional balance is maintained in cells	(Budakli et al., 2010); (Lee et al., 2013); (Hajiboland et al., 2014); (Jiang et al., 2017); (Gupta & Huang, 2014); (Gao et al., 2016); (Wakeel et al., 2011); (Isla & Aragüés, 2010)
Osmoregulation	By accumulation of organic and inorganic ions like proline, betaine, glycine betaine, and β-alanine betaine	Osmotic potential of cell is maintained	(Hashem et al., 2016); (Perri et al., 2017)
Stomatal conductance regulation	Increased production of phytohormones, elicitors and metabolites cause closure of stomata	Water loss is prevented from plant	(Mohamed et al., 2020); (Agurla & Raghavendra, 2016); (Prodhan et al., 2020); (Bharath et al., 2021)
Phytohormonal regulation	Absicic acid, methyl jesmonate, ethylene and salicylic acid are increased	Water loss is reduced and salt tolerance increased	(Yu et al., 2020); (Ryu & Cho, 2015); (Bharath et al., 2021); (Delgado et al., 2021)
Molecular mechanisms	Overexpression of some genes that encode for antioxidant enzymes,	Activity of antioxidant enzymes is increased to detoxify ROS	(Gupta & Huang, 2014); (Chen et al., 2019); (Uddin et al., 2013); (Gupta & Huang, 2014)

Maintenance of ionic balance

Ionic homeostasis is the maintenance of optimum levels of ions in cells in order to normalize the cellular metabolic processes. In salinity one of the major issues is the high uptake and accumulation of sodium ions in cell sap that interferes with the uptake of other ions like potassium, calcium, nitrogen, magnesium, phosphorus, zinc, iron and copper. This ionic toxicity can lead to nutritional imbalances in plants and can change the metabolic processes (Budakli et al., 2010). So, one of the mechanisms to maintain ionic balance that is naturally adopted by plants is the movement of extra sodium into the vacuoles from cytosol so that balance of sodium is maintained in cytoplasm (Lee et al., 2013). There are specific Na+/H+ antiporters in the tonoplast of vacuoles that move sodium ions in and hydrogen ions to outside the vacuole (Hajiboland et al., 2014). Study has reported that in salt-stressed plants of maize expression of NHX_1 gene is upregulated to increase the numbers of Na+/H+ antiporters in cells (Jiang et al., 2017). SOS (salt overlay sensitive) stress signaling pathway is also activated in salt stressed plants that has three proteins named as SOS_1, SOS_2, SOS_3. These proteins also result in expression of genes that encode for Na+/K+ antiporters (Gupta & Huang, 2014).

Another aspect of ionic imbalance is decreased concentration of potassium ions in cells due to high intake of sodium ions. Na+/K+ ratio is disturbed due to sodium ion accumulation so one strategy is the maintenance of higher K+/Na+ ratio in cells (Gao et al., 2016). More K+ ions are accumulated in the cell and their transport out of the cell is inhibited by the expression of CED-9 gene (Wakeel et al., 2011). Secondly sodium ions and chloride ions are moved more toward stem and leaf sheath and their transport is prevented toward leaf blade to avoid their toxic effects there (Isla & Aragüés, 2010).

Osmoregulation

Osmoregulation is the key strategy of plants to cope up with salt stress. It is the maintenance of osmotic potential of cells as well as whole plants. Many mechanisms have been adopted by the plants to regulate osmotic potential (Hashem et al., 2016). Plants accumulate many inorganic and organic components in them to maintain osmotic potential. Some of these contents are proline, proline betaine, glycine betaine, and β-alanine betaine and soluble sugars like fructose, glucose, fructans, raffinose, and trehalose. These solutes lower the water potential of plants without reducing the actual water content of plants (Perri et al., 2017). Other adaptation has been discussed for the maintenance of ionic balance in cells to reduce osmotic stress. These mechanisms prevent the outward movement of water from the cell.

Stomatal conductance regulation

Major need in salt stressed plants is to conserve water and avoid water loss from plants as the rate of water absorption is already lower in them. Major source of water loss is the evapotranspiration through the stomatal opening. Stomatal closure is the adoption strategy of plants to prevent water loss. In salt stressed plants, production of abscisic acid (ABA) is higher that moves from roots to shoots and reaches to guard cells of stomata. ABA results in closure of stomata that also decrease the rate of carbon dioxide assimilation, activity of Rubisco and rate of photosynthesis (Mohamed et al., 2020).

Compounds other than ABA can be involved in the stomatal closure during salt stress. These are certain hormones, elicitors and metabolites. Hormones are methyl jasmonate, salicylic acid and ethylene that increase the pH, ROS (Reactive Oxygen Species), NO (Nitrogen Oxides) and Calcium ion and resulting in stomatal closure (Agurla & Raghavendra, 2016). Elicitors that are involved in stomatal closure are salicylic acid, chitosan, flagellin 22, harpin, and cryptogein through the production of ROS and NO (Prodhan et al., 2020). Metabolites accumulated under salt stress are Allyl isothiocyanate (AITC), proline, and polyamines that result in partial closure of stomata (Bharath et al., 2021).

Phytohormonal regulation

Plant hormones play an important role in regularized growth and development of plants but in salt-stressed conditions some of the growth hormones like gibberellic acid and auxin are reduced and result in growth retardation. But certain other hormones like methyl jasmonate, abscisic acid, salicylic acid and ethylene are increased to overcome salt stressed conditions (Yu et al., 2020). ABA is known to be a stress hormone of plants and it has been reported that endogenous production of ABA is increased by overexpression of its genes to withstand salt stress. Zeaxanthin oxidase, 9-cis-epoxycarotenoid dioxygenase, ABA-aldehyde oxidase and molybdenum cofactor sulfurase are the genes that are activated in salt stressed plants and result in overproduction of ABA (Ryu & Cho,2015). Role of ABA is in the water regulation by closing the stomata and by maintaining osmolytes concentration. It also regulates the growth of plants (Bharath et al., 2021).

Just like ABA production of methyl jasmonate is also increased in plants growing in saline soil. Many studies have reported the overproduction of methyl jasmonate in salt stressed plants and having a role in elevating salt tolerance. They act as a protectant against salt stress (Delgado et al., 2021). Other hormones like Salicylic acid and ethylene are also produced in maize plants to cope up with salinity, increase plant growth and to conserve water loss.

Molecular mechanism of salt tolerance

A wide variety of mechanisms at the molecular level have been adopted by the plants to survive in salinity. They may involve up and down regulation of some genes. The genes that encode for antioxidant enzymes like superoxide dismutase, glutathione peroxidase, glutathione reductase, catalases are up regulated to increase the production of antioxidant enzymes and to activate the anti-oxidant defense mechanisms (Gupta & Huang, 2014). *Zmodc* and *Zmspds2A* are two genes that have been reported in maize plants whose expression is increased to accumulate polyamine and spermidine. These help in salt tolerance in maize (Chen et al., 2019).

Alteration in chemical composition of cell walls is also an adoption to salt stress. The non-methylated uronic acid is less accumulated in the cell wall of salt stressed plants and it contributes to salt tolerance. The process of cell wall acidification is also enhanced in saline conditions (Uddin et al., 2013). Examples of salt responsive genes are ion transport or homeostasis genes (e.g., *SOS* genes, *AtNHX1* and *H+-ATPase*), senescence-associated genes (e.g., *SAG*), molecular chaperones (e.g., *HSP* genes), and dehydration related transcription factors (e.g., *DREB*) (Gupta & Huang, 2014).

Management practices to mitigate salt stress in Maize

Salinity is one of the devastating factors for the crops that decrease their production and affect the economy of the people. Scientists are looking forward to the method that is reliable, cheap, efficient and environment friendly for mitigation of salinity effects. Some of the most used and inexpensive methods are listed in Table 5 and their details are as under:

Reclamation of salt affected soil

A wide range of approaches can be used for the reclamation of salt affected soil and to make it productive and fertile. Salt affected soil has a higher amount of soluble salts so approach being used depends on level of salinity, time required and soil characteristics (Osman, 2018). First appropriate method is the leaching out of excess salts from the soil to make it less salty so that water could be available to plants. Leaching process depends on initial salt content, nature of salts, EC required after leaching and quality of water. Leaching process is done by the water drainage through saline soil that removes the excess of salts and makes the soil less salty (Machado & Serralheiro, 2017).

Soil reclamation can also be done by using organic or inorganic soil amendments. Chemicals that are used in soil reclamation are salicylic acid, boron, potassium, phosphorus, biochar, silicon, cow dung and solid waste (Gattullo et al., 2016). The most used soil amendment is the use of organic manure. It is the most effective and less costly method to reclaim the salt affected soil. It undergoes quick release of nutrients when combined with other chemical fertilizers and this technique is accepted by farmers on worldwide level (Roy & Kashem, 2014). Exogenous application of salicylic acid increases growth rate in maize plants and it also increases peroxidase activity in the root area of plants. Increase in total protein content and chlorophyllin pigment has also been observed in maize as a result of salicylic application (Purcarea et al., 2010). Application of biochar in soil increases potassium content, soil moisture, plant available phosphorus and biomass of maize plants. It also increases soil PH and alleviates nutrient stress tolerance in maize plants (Pandit et al., 2018). Inorganic fertilizers make the availability of nutrients easier but they have certain adverse effects on underground water and they cause its pollution. So organic amendments are more preferred as they are environment friendly, easy to use, cheaper in cost and good in production (Scotti et al., 2014).

Exogenous application of plant growth regulators

Plants have growth promoting hormones named as auxin, gibberellin and cytokinin while also have growth retarding hormones named as abscisic acid and ethylene. But in salt stressed plants growth promoting hormones are decreased while growth retarding hormones are increased. So, growth regulators can be applied exogenously to ameliorate salt tolerance (Latef et al., 2021). Plant growth regulators that are most commonly used are aminoethoxyvinylglycine, ethephon, i-methylcyclopropene that improves growth quality of plants and inhibits synthesis of more ethylene (Hussain et al., 2019). Auxin and cytokinin application in combination or alone result in improved plant growth and morphological parameters (Ghorbani et al., 2011).

Exogenous application of gibberellic acid in maize can improve seedling length, dry weight, fresh weight, soluble protein, emergence rate, chlorophyll content and peroxidase activity (Ali et al., 2021). Combined application of indole acetic acid and kinetin enhance physiological parameters in maize plants. They increase potassium and calcium concentrations in plants while decreasing sodium content to overcome ionic toxicity (Kaya et al., 2010).

Seed priming

Seed germination is the most critical stage of plant growth and it is the most commonly affected parameter of plants in salt stressed condition. Due to low water availability in soil and higher osmotic stress in seeds they are not able to absorb enough water and germinate. Seed priming is the most effective and most common method used to deal with salt stress (Rehman et al., 2015). Seed priming is the pre-soaking treatment of seeds either in water or any other chemical to increase germination rate and to improve other physiological parameters of plants (Lutts et al., 2016). Seed priming improves germination rate, synchronizes germination events and a faster seedling emergence rate has also been observed in primed seeds (Ali M., & Khan, 2016). The major problem of less water absorption of salt stressed seeds is tackled by seed priming as it helps out the seed to imbibe more water and faster the rate of germination. The overall effect of seed priming is on seedling vigor, that is the overall performance of seed during germination and growth period (Pawar & Laware, 2018).

Several types of seed priming have been devised by researchers and scientists that are being used now-a-days. There are three types of seed priming; Osmopriming, hydropriming and hormonal priming (Selvarani & Umarani, 2011). Hydropriming is the most efficient and inexpensive way of priming, it involves the soaking of seeds in water before sowing and then drying to required moisture (Lemmens et al., 2019). Hydro priming has a pronounced effect on germination percentage, germination index, germination rate, germination vigor index, emergence rate and promptness index. It causes the seeds to absorb water efficiently and salt stress is coped up in such seeds (Shukla et al., 2018). Results of (Ahammad et al., 2014) showed that hydropriming in maize weeds improved the germination percentage and germination index while mean germination time was decreased by it.

Osmopriming is also a widely used method in mitigation techniques that involve soaking of seeds in osmotic solutes before sowing. These osmotic solutes have low water potential that cause low intake of water by seeds and early germination process is started in them. But radicle emergence is slowed down in the soaking period (Singh et al., 2014). Chemicals that are used in osmopriming are potassium nitrate, ascorbic acid, salicylic acid, glycerol, mannitol, sorbitol, polyethylene glycol, sodium chloride, potassium chloride and so on (Yacoubi et al., 2013). (Rehman et al., 2015) have reported the use of osmopriming with moringa leaf extract (MLE), calcium chloride and potassium chloride in spring maize varieties and showed results that MLE priming improved electrical conductivity, relative leaf water content, chlorophyll content, plant height, seeds weight and number of seeds per cob followed by calcium chloride and then by potassium chloride.

Hormonal priming is done with the soaking of seeds in hormones that are growth regulators that have effect on the seed metabolic processes and growth occurs in presence of growth regulators (Rhaman et al., 2021). Hormonal priming is done with auxin, gibrillin, abscisic acid, cytokinin, indole acetic acid, salicylic acid and polyamines (Lutts et al., 2016). Priming with indole acetic acid (IAA) improves cell division, photosynthetic activities, lateral root initiation and flowering (Sneideris et al., 2015). (S et al., 2018) has used combination of hormones including Gibberellic acid, Sodium nitroprusside (SNP), Abscisic acid and kinetin on maize seedling and showed that this combination of hormonal priming improves fresh and dry biomass of plants as well as germination rate is increased in them.

Table 5 Management strategies to mitigate salt stress in maize crop

Mitigating strategy	Mechanism of action	Advantages/disadvantages	References
Soil Reclamation	Excess of salt is removed from soil by leaching, and organic & inorganic soil amendments are used for nutrient supply	Leaching process can cause water logging and similarly inorganic amendments can cause water pollution	(Osman, 2018); (Machado & Serralheiro, 2017); (Gattullo et al., 2016); (Roy & Kashem, 2014); (Purcarea et al., 2010); (Pandit et al., 2018); (Scotti et al., 2014)
Exogenous application of plant growth regulators	Aminoethoxyvinylglycine, ethephon, i-methylcyclopropene, Auxin, cytokinin, gibbrilic acid, indole acetic acid and kinetin are applied to improve physiological and biochemical processes	This technique is only useful at the later stage of growth and can't be used for germination of seeds	(Latef et al., 2021); (Hussain et al., 2019); (Ghorbani Javid et al., 2011); (Ali et al., 2021); (Kaya et al., 2010)
Seed priming	Osmopriming, hydropriming and Hormonal priming is used to improve and synchronize germination events	It has not as much drawbacks but it just requires correct selection of priming agent and proper way of priming	(Lutts et al., 2016); (Ali M., & Khan, 2016) ; (Pawar & Laware, 2018); (Lemmens et al., 2019); (Shukla et al., 2018); (Ahammad et al., 2014); (Singh et al., 2014); (Rehman et al., 2015); (Rhaman et al., 2021); (Lutts et al., 2016); (Sneideris et al., 2015); (S et al., 2018)
Molecular and Genetic breeding techniques	Salt tolerant genes from tolerant genotypes are engineered in salt sensitive genotypes for example ABP2 gene and ZmPMP3 gene	This is very skillful technique and can be only carried by scientists in properly equipped laboratories	(Fu et al., 2012); (Zong et al., 2018); (Nongpiur et al., 2016); (Rajurkar & Shende, 2013); (S. Ali et al., 2019)

Molecular and genetic breeding techniques

Maize is a moderately salt sensitive crop but there are some salt tolerant genotypes of maize that have developed tolerance against salt stress. These salt tolerant genotypes have less accumulated toxic ion while concentration of other ions like potassium and calcium are higher in them. Screening is done for these salt tolerant genotypes and then used for breeding purposes (Ali et al., 2019). For screening of salt tolerant many molecular techniques are used including checking the Na^+/H^+ antiporters in cells, ionic concentration, cell wall acidification and osmotic regulation (Rajurkar & Shende, 2013). Gene transfer of salt tolerant gene from one genotype to another or from one species to other species through genetic engineering is also an efficient technique to induce salt tolerance in salt sensitive genotypes (Nongpiur et al., 2016). (Zong et al., 2018) have identified and isolated ABP2 gene in maize that is up regulated by the ROS, drought or salt stress. Then this gene was engineered in the Arabidopsis plant to induce salt tolerance in them. Eight ZmPMP3 genes were cloned from maize that encodes for plasma membrane protein 3. These proteins are present in plasma membranes in salt tolerant plants and regulate the ionic intake and uptake of plants (Fu et al., 2012).

Conclusion and future prospective

Soil salinity is one of the overwhelming stresses on crops that affects morphological and physiological parameters of plants, decreasing their yield and productivity. Plants have naturally evolved resistance mechanisms to overcome the devastating effects of salinity that includes exclusion of toxic chemicals and maintenance of osmotic balance. Some mitigation techniques are also being used by scientists and farmers to ameliorate salt tolerance in maize crop. These include the use of soil reclamation techniques, seed priming, inorganic and organic fertilizers, use of plant growth regulators and use of molecular and genetic techniques to induce salt tolerance in maize crop. From this review article it is concluded that seed priming is the easiest mitigation technique which is most effective, less time required and easily carried by farmers. On the other hand, it is not so costly and does not require much skilled handling.

A lot of research has been done on the morpho-physiological effects of salt stress on maize crop and its tolerance mechanisms but still there is need to do research work on effects of salinity on reproductive parameters of maize. A wide variety of techniques has also been devised to increase salt tolerance and to cope up with salinity. Further research is required to develop such approaches and techniques that can be easily handled, time saving and used to evaluate and screen salt tolerant varieties. Easy and time saving mitigation strategies should be developed to overcome salinity in soil and to improve growth of plants. Genetic transformation is an emerging field but costly. However, scientists having the facilities should incorporate salt tolerance genes to improve the ability of crops to tolerate this abiotic stress.

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