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Chapter

Salinity Stress in Maize: Effects of Stress and Recent Developments of Tolerance for Improvement

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Abstract

Soil salinity has emerged as a global threat to sustainability of farming systems by deteriorating the quality and productivity of crops particularly in the coastal regions of the world. Although, as a C4 plant, maize (*Zea mays* L.) has ability to tolerate a medium level of salinity; but initial growth stages of maize are sensitive to salinity stress. Therefore, it is crucial to expand our understanding pertaining to maize response to salt stress and tolerance mechanisms for devising approaches to enhance maize adaptability in saline environments. Moreover, maize crop undergoes several physiological changes and adapts some mechanism to overcome the salinity stress. Different mitigation strategies like application of chemicals, plant growth-promoting hormones, and use of genetic and molecular techniques are used to manage salinity and may ensure crop productivity under changing climate. This chapter aimed to assess the recent advancement pertaining to salinity stress influence on the physio-biochemical processes in maize and to draw the relationship between yield components and salinity stress. In addition, current study also highlights research gaps by focusing the seed enhancement techniques, phytohormones exogenous application and genetic improvement of maize under soil salinity.

Keywords: Salt stress, adverse effects, maize, productivity, seed enhancement

1. Introduction

Among various abiotic stresses, salt stress has posed one of the most severe threat to modern commercial oriented and profit-driven crop production at a global scale [1–4]. Besides soil salinity, utilization of saline water for irrigation purposes, particularly in the

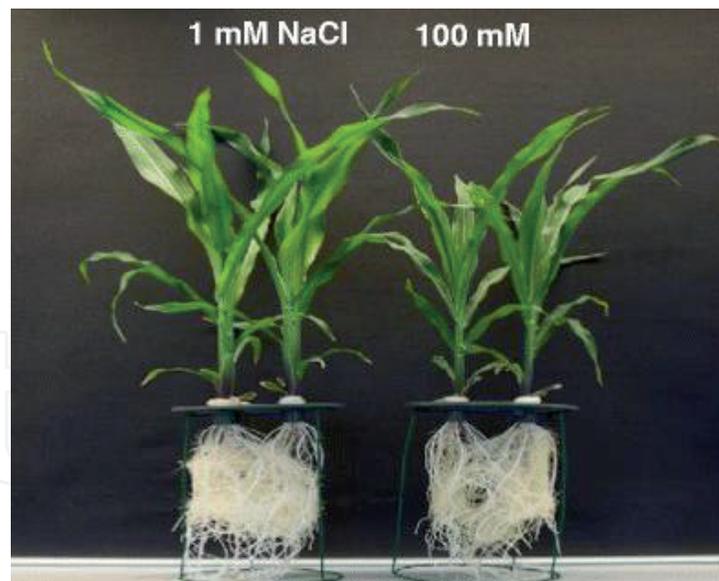


Figure 1.
Effect of salt stress on the initial growth of maize (adapted from Farooq et al. [12]).

low-lying coastal regions of many countries, has also been identified as a major yield-limiting factor for boosting agriculture production [5, 6]. The detrimental impacts of salt stress manifest through a reduction in the relative water potential of plants which causes decline in plants growth [7], coupled to a negative effect in soil and water quality both in the short and long term [8, 9]. Salt stress is associated with the moisture stress that decreases plant growth and ultimately reduces plant yield even at soil moisture contents that are not limiting for crop productivity (Figure 1) [10, 11].

Similar to other C4 plants, maize is able to grow in both saline and non-saline conditions due to its stress adaptive potential and relatively tolerance against salinity [12–14]. Although salinity adversely affects maize growth and yield attributes throughout most of the plant cycle, the final impact on plant productivity depends upon the length and severity of the stress and the growth phase when the stress occurs [15, 16]. In general, and similar to the case for other row crops, the initial growth stage of maize is highly sensitive to salt stress. In a hydroponically grown study, Farooq et al. [12] observed the growth of roots and shoots of salt-treated (1.0 and 100 mM NaCl, applied one week after transplanting) maize variety cv. ‘Pioneer 3906’. Authors reported a significant reduction in the plant height and dry matter biomass of plants treated with the highest salt concentration just 21 days after the beginning of the salt soaking study [12]. However, lower salt concentrations can severely impact normal crop growth and several studies have demonstrated that very low salt concentrations can reduce the growth cycle of maize plant due to oxidative stress before the occurrence of sodium toxicity in the plant [17–19]. The objectives of this chapter are to discuss a) the current and most recent knowledge regarding the influence of salinity stress on physio-biochemical processes and yield components in maize, and b) the seed enhancement technologies, phytohormones exogenous application and genetic improvement of maize against soil salinity stress.

2. Adverse effects of salinity on growth and development of maize

2.1 Effect on germination

Seedling establishment is an important phase in the plant life cycle. Salt stress adversely affects seed germination [20], due to the decrease in the osmotic potential

created in the soil solution that prevents the entry of water into the seed [21]. During seedling establishment, intake of sodium and chloride ions causes toxicity in the plant cells, thus reducing seed germination rates and the growth of seedlings that have already germinated [22]. Besides its negative impact in the germination rates, salinity stress also delays the overall germination process, thus reducing the survival chances of those seeds that were able to germinate [23, 24]. Because of its potential to drastically reduce crop productivity, it is of paramount importance to recognize these early deleterious impacts of soil and water salinity in plant growth and development [25].

Salinity reduces seedling establishment by increasing the oxidative stress through the absorption of Na^+ and Cl^- ions in the seeds that cause toxicity in the embryogenesis and protein synthesis. Maximum oxidative stress caused by Na^+ and Cl^- ions toxicity during germination lowers or stunts the germination of plants [26]. In case of maize production, just Na^+ toxicity was found more detrimental in reducing the germination under salt-stressed environments.

Under arid and semi-arid conditions salt stress is commonly considered as the more threatening factor reducing the seed emergence rates and the overall crop stands [9, 27, 28]. Therefore, salinity constitutes one of the most significant abiotic factors limiting crop productivity, while changing climate scenario has even further worsened the situation [29]. The ability of seeds to germinate at high salt concentrations in the soil is of crucial importance for the survival of many plant species. However, the effects of salinity are modified by its interactions with other environmental factors such as temperature and light [30]. In saline habitats, satisfactory seed germination typically takes place after high precipitation events, when soil salinity is reduced [31]. Seed priming stimulates numerous metabolic processes involved in the early phases of germination, and it was observed that seedlings from primed seeds can grow more vigorously and perform better under adverse environmental conditions compared to non-primed seeds [32].

2.2 Effect on maize growth

El Sayed, [33] observed dramatic decreases in maize plant root elongation, plant height, leaf area, photosynthesis, mitotic division and root and shoot biomass in a sandy soil under salt stress conditions. Salinity promotes suberization of the hypodermis and endodermis, and the Casparian strip develops closer to the root tip compared to roots growing in non-saline soils [34]. Although roots are the first organ exposed to salt stress, shoots are more sensitive to salt stress [35]. Salinity reduces shoot growth by suppressing leaf initiation and expansion, as well as internode growth, and by accelerating leaf abscission [36]. Salt stress rapidly reduces leaf growth rate due to a reduction in the number of elongating cells and the rate of cell elongation [37, 38]. As a salt-sensitive crop, shoot growth in maize is strongly inhibited in the first phase of salt stress [38]. Schubert et al. [39] observed stunted maize growth with dark green leaves without any toxicity symptoms during the first phase of salt stress, owing to impaired extension growth as osmotic adjustment and turgor maintenance were not limiting. Likewise, growth of salt-resistant hybrids has shown that it was not turgor but cell wall extensibility which restricted cell extension growth during the first phase of salt stress [39].

Salt stress may also displace Ca^{+2} ions from plasma membrane-binding sites, thus causing membrane leakiness as a primary cellular response to salt stress [40]. When the integrity of the plasma membrane is affected by high salt concentrations in soil, a cell wall acidification process occurs due to the reduction in the cell wall ability to pump protons out across the intact plasma membrane [41]. Conversely, pH in the apoplastic space tends to increase in salt-sensitive maize genotypes subjected to salt stress and this reduces the extension growth of the cell due to

less acidification of the apoplast [41, 42]. Comparing salt tolerant and susceptible genotypes of maize, Pitann et al. [43] found that salt-tolerant genotypes better regulated hydrogen ions concentration and decreased the pH in the apoplastic space, while also loosen the cell wall turgidity according to the acid growth theory [44]. According to this theory, the increased in the cell wall expansion triggers a protein synthesis process that ultimately results in cell growth. The enzymes that are responsible for the loosening process in the cell wall and the regulation of cell elongation are present in the apoplastic space of cells located in the leaves [42]. The extent to which these enzymes will loosen the cell wall for further extension depends upon the acid concentration in the apoplastic space and the existence of a cell wall pH under 5 [45, 46]. Research shows that, when grown under salt stress conditions, the amount and activity of β -expansion proteins decreased in salt susceptible genotypes of maize, while it was only slightly affected in salt-tolerant genotypes [47, 48]. In general, β -expansion proteins have been more heavily studied than α -expansion proteins in salt-stress related research [49]. These β -expansion proteins are responsible for important cell functions and have a specific set of matrix polysaccharides and structural proteins in maize [49].

Early in the growth cycle, high salt concentrations reduced the growth of tissues in corn which may be partially accountable for a reduction in the overall photosynthetic capacity of the plant [50]. Moreover, salt stress has shown to produce structural variations in the cell wall that alter its correct functioning [51]. For instance, salt stress stimulates the production of ROS (Reactive Oxygen Species) such as peroxidase and hydrogen peroxide in the cell apoplastic space, and this increases the biosynthesis of diferulates which inhibits maize cell wall growth [52–54]. Moreover, increased in the ROS results in peroxidation of lipid and DNA damage [55–57]. In other studies, a temporary increase in the concentration of apoplastic peroxidase terminated cell wall elongation [58, 59], and increased the oxidation of phenolics compounds in maize [60]. A persistent salt stress condition across the plant growth cycle can result in a significant decrease in the length of the shoots and the extent and duration of the flowering process in the plant, which ultimately affects the reproduction and the productivity of crops. In this context, salt stress resulted in the deterioration and further abscission of old leaves of plants while the growth of young leaves was not affected by salt stress at grain cob initiation stage [1].

2.3 Effect on development and yield

The number and weight of kernels are the two most important yield components to calculate grain yield in maize [61–64]. In a recent study, and compared to non-saline conditions, a salt concentration of 100 mM NaCl applied at the reproductive phase of maize reduced the kernel yield and the kernel weight by 25% and 8%, respectively (**Figure 2**) [65]. Katerji et al. [66] studied the effect of three irrigation water treatments [i.e., fresh, unsalted water; 15 and 30 mEQ l⁻¹ (NaCl and CaCl₂)] in maize yield and yield components in a clay and a loamy soil. Compared to non-saline treatment, authors found that 15 mEQ l⁻¹ reduced maize grain yield by 11.3% in the clay soil through a reduction of 7.6% in the kernel set without changes in the kernel weight. Conversely, the 15 mEQ l⁻¹ salt treatment did not affect grain yield in the loamy soil. Application of 30 mEQ l⁻¹ salt treatment reduced the grain yield by 24.5% in the clay, and by 21.4% in the loamy soil as a result of decreases in both the kernel set and kernel weight in the two soils.

Photosynthesis reduction and sink limitation induced by salinity are among the main reasons for poor kernel setting and reduced grain number [67]. Under salt stress conditions, a sink limitation disrupts kernel setting more than the resulting reduction in the photo-assimilation production in maize. Research showed that the

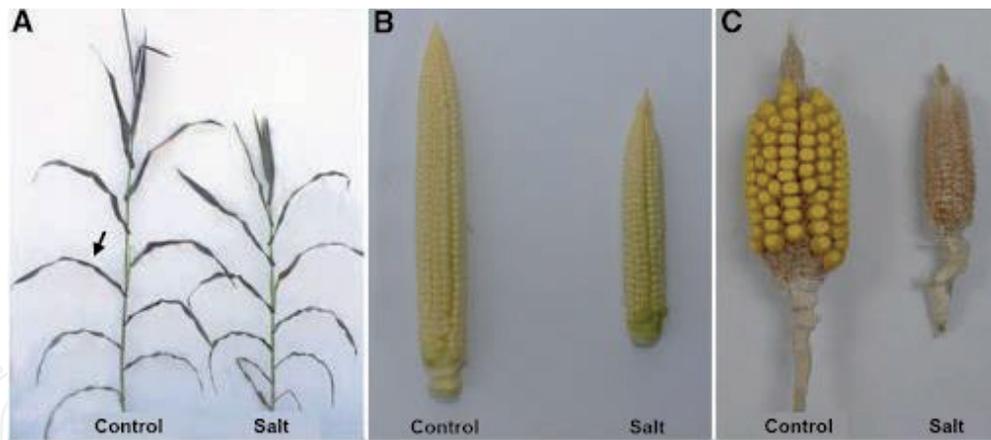


Figure 2. Salt stress effects on maize plant growth and yield (from Kaya et al. [65]). A: Effect of salt stress on growth; B: cob length; and C: grain filling of maize.

salt stress-induced reduction in the sink activity in maize causes a reduction in the acid invertase activity, which further reduces the final grain number in maize [68]. At the eco-physiological level, however, a decrease in the translocation of assimilates from leaves to the emerging grains is the main driver for poor kernel set and reduced grain weight, and thus final grain yield, in maize plant stands subjected to salt stress conditions [69].

In salt-stressed maize plant, growth is affected by lack of nitrogen due to the antagonistic action of nitrate ions with chloride ions [34, 70]; hence, maize yield significantly improved with the addition of nitrogen under salt stress. Application of nitrogen in the amount of 120 kg ha^{-1} neutralized the harmful effects of salinity; in particular, it improved nitrogen absorption, growth and productivity under of salt stress conditions [71].

2.4 Effect on grain quality

Different environmental conditions can greatly affect the grain quality in maize [72]. Among these, the negative impact of salt stress in grain quality has not been extensively studied. Working with five saline irrigation levels [1, 2, 3, 4, and 5 g L^{-1} of total dissolved solids (TDS)] in a 2-yr study in China, Li et al. [73] found no difference in the oil, crude fiber and ash contents of maize grain. Conversely, grain moisture and starch content decreased with increased salinity, with maximum values occurring with 1, 2 and 3 g L^{-1} of TDS in both cases, while protein content increased with increased salinity, reaching maximum values $>12\%$ with 4 and 5 g L^{-1} of TDS. While the impacts of different salinity treatments were antagonistic for starch and protein content, two of the key quality components in maize grain, salt levels in the irrigation water should balance the content of each component. Low grain moisture content can be beneficial for storing purposes, as these conditions are detrimental for proliferation of fungal pathogens, which can cause mycotoxin contamination and reduction in the maize grain quality (Table 1) [74].

Cucci et al. [75] found no difference in the kernel composition due to irrigation water quality in the first year of a study conducted in Italy. Contrarily, in the third year, brackish water irrigation increased the grain protein content by 6.9% and decreased the moisture content by 9.3% compared to grain irrigated with freshwater, which is similar to the findings from Li et al. (2019) [73]. Finally, there was no effect of irrigation scheduling and the interaction among salinity and irrigation scheduling on grain quality either in the first or the third year under study.

Years	Water Quality	Protein %	Starch %	Fats %	Grain Moisture %
1st	Brackish water	9.1a	72.1a	4.2a	15.2a
	Fresh water	8.9a	71.8a	4.1a	15.5a
3rd	Brackish water	9.2a	71.6a	4.1a	14.6b
	Fresh water	8.6b	71.7a	4.3a	16.1a

Different letters indicate significant difference according to Duncan test ($p = 0.05$).

Table 1.

Grain quality of maize as affected by the different quality of irrigation water in the first and third year of crop rotation [75].

3. Recent approaches for improvement of maize tolerance under salinity

3.1 Application of hormones and osmoprotectants

Exogenous applications of growth hormones and osmolytes have been found to be effective to cope against the negative impacts of soil and water salinity. The role of plant growth regulators and osmoprotectants under salt stress is important in modulating physiological responses leading to adaptation to such unfavorable environments. Accumulation of osmolytes under low water potential conditions, such as those occurring soils with elevated salt concentrations, helps to maintain the plant water status in a process known as osmoregulation [76]. More than 20 years ago, osmoprotectants were chemically grouped as amino acids (proline), ammonium compounds (glycine betaine), polyols and sugars (mannitol, dononitol, trehalose, fructans) [77]. In a recent study, osmoprotectants were classified into two major groups, namely organic (eg. glycine betaine, proline, sugars, and proteins) and inorganic (eg. Ca, K, PO₄, NO₃, SO₄) osmoprotectant solutes preserving water without impairing the regular metabolism of the plant [78]. Among them, proline, glycine betaine, and mannitol are commonly found in cytosol and chloroplast in plants. Under stressed environments, exogenous application of osmoprotectants act to maintain the regular plant cellular functions [79–81], by playing key roles in regulating the enzyme activity, ROS homeostasis, maintaining the membrane integrity, and balancing the ionic transport across the cell membrane [82].

The exogenous application of gibberellic acid (GA) and cytokinin (CK) at the maize vegetative stage was effective to remediate the damage in the cellular membranes of maize plants subjected to water deficit stress [83], by decreasing the electrolyte leakage and lipid peroxidation [84].

Similarly, exogenously applied GA, CK and auxin improved the tolerance to water deficit resistance in maize plants growing in saline soils by mitigating the membrane oxidative damage and improving the overall plant water status [85]. Moreover, application of GA, Indole-acetic acid and proline combined with organic amendment enhanced heavy metal tolerance and increased protection against oxidative stress in maize compared to non-applied control, thus providing a promising approach as an osmoprotectant that could be used in saline soils [86].

Salicylic acid (SA) plays dual roles as both a plant growth regulator and an antioxidant, improving crop performance under abiotic and biotic stresses [87, 88]. Salicylic acid-induced antioxidant system was reported in maize in water deficit environments [89]. Foliar application of SA in maize has a potential to increase the relative water content and membrane stability index in maize grown under water deficit environments [90]. Moreover, in salt stressed maize plants, exogenous application of SA improved plant growth, antioxidant enzyme contents and stabilized the overall photosynthetic process [91]. In this regard, foliar application of SA in maize

seedlings reversed the negative impacts of soil salinity in the plant gas exchange, rubisco activity and photosynthetic efficiency [92, 93], while also increasing the production of soluble sugars, proline and nutrient uptake particularly K^+ [94]. When SA was applied to roots, increases in the photosynthetic rates, gas exchange levels, and internal CO_2 exchange and grain yield of maize were observed in saline soils [95, 96]. Pre-treatment of maize seeds by exogenous application of SA (2 mM) exhibited improved seedling emergence and stand establishment maize [97].

The exogenously applied methyl jasmonate (MeJA) can ameliorate the plant tolerance to abiotic stresses such as drought and salinity by enhancing the defense-oriented metabolism of plants [98, 99]. Pre-treatment of maize seeds with MeJA can suppress the harmful effects of water stress by maintaining the total protein, proline, carbohydrate contents and antioxidant activities under saline conditions [100]. Additionally, seed and foliar pre-treatments with exogenous MeJA showed positive effects on drought-induced oxidative stress responses of maize seedlings by modulating the levels of osmolytes, endogenous abscisic acid (ABA), and the activities of antioxidant enzymes [101].

3.2 Seed priming

The occurrence of an even and fast germination process has long been considered as a critical stage for final yield determination in most crops [102]. The seedling stage of maize plant is more sensitive to salinity [103] than mature stages [104]. Seed priming entails pre-sowing seed treatment with different priming agents including water, growth regulators [105], which facilitates the germination process by increasing the energy metabolism of the plant, promoting a more efficient mobilization of food reserves, enhancing expansion of the seed embryo [106], inducing formation of stress-responsive systems such as heat shock proteins, catalase and other antioxidant scavenging enzymes and upregulating the genes encoding peroxiredoxin [2, 107]. Increased germination rate and vigorous seedling establishment have been documented for primed seeds especially hydro-priming, and priming with growth regulators [108, 109]. The use of seed priming in the form of inorganic chemicals, plant extracts or microorganisms is one of the most efficient technologies to improve the germination rates and the synchronization of seedling emergence in plants [110]. Seed priming technique tend to boost water status of the seed which leads to activation of the pre-germination metabolism of the seed. In the second stage, the seed is dried to prevent radicle emergence before seed sowing [111].

Seed priming techniques utilize different osmotic solutions as seed priming agents including inorganic salts, sugars, growth regulators and polyethylene glycol [111]. Broadly, there are two seed priming techniques, known as uncontrolled hydration or hydro-priming [112], and controlled hydration, which includes methods such as osmotic priming, solid matrix priming, and hormonal priming [113]. Among others, polyethylene glycol (PEG), chlorides, sulphates, nitrates, glycerol, sorbitol have also been commonly used as osmotic priming agents having germination enhancing effect for different cereals including maize [23].

Nutrient priming with various inorganic compounds has been effectively applied to enhance germination and growth of maize under saline environment. For example, KNO_3 has shown better establishment of seedlings at low temperatures in maize [114]. Micronutrients have been reported as nano-seed priming agents for boosting germination percentage and seedling development and vigor [115]. Also, priming maize seeds with NaCl before sowing induced physiological and biochemical changes thereby enhancing salinity tolerance and better performances under varying degree of saline environments [116]. Priming of maize seeds with $CaCl_2$ increased the germination rate, and both the fresh and dry biomasses of plumules and radicles in

maize compared to untreated control and hydro primed seeds under salinity stress [117]. Further, authors measured significantly higher concentrations of Na^+ , K^+ and Ca^{2+} in growing seedling tissues when seeds were primed with inorganic salts such as NaCl , KCl , or CaCl_2 [117]. Maize seeds priming with 1% ZnSO_4 exhibited improved plant growth, increased final grain yield and enriched Zn^{2+} contents in seed on soils with limited Zn^{2+} availability, and a more efficient translocation of Zn^{2+} to growing shoots during germination and early seedling development [118], in saline environments. Moreover, use of Zn as a seed primer increased the accumulation of Zn^{2+} in the aleurone layer of maize seeds, and resulted in a higher plant biomass production and mineral nutrient uptake in plants subjected to salt stress [119].

Maize seeds primed by SA (2 mM) exhibited improved seedling emergence and establishment maize under salt stress [97]. Kinetin and indole acetic acid application on foliage negate the harmful effects of salt stress, while it does not affect maize plant salinity resistance. In addition, the salt content increases the sodium concentration in corn leaves at the disbursement of potassium and calcium, while kinetin and indole acetic acid foliar applications correct these effects and raise the potassium and calcium content in the leaves. Thus, 2 mM concentration of kinetin and indole acetic acid foliar application counteracted the adverse effects of salt on maize growth and yield by increasing membrane permeability and absorption of essential nutrients [40]. Yang et al. [120] reported that exogenous application of glycine betaine on maize plant under salt stress enhanced growth, net photosynthesis, leaf water content, and quantum yield of photosynthesis.

3.3 Genetic improvement of maize tolerance to salinity stress

In the recent past, molecular marker-assisted selection and other biotechnological techniques are being used in the context of the physiological basis of stress tolerance along with conventional breeding strategies to increase tolerance to abiotic stresses (heat, drought, and salinity) in maize. However, poor success in establishing maize cultivars tolerant to stress is mainly due to poor screening and selection techniques, poor selection criteria, and poor understanding mechanism of stress tolerance. However, some reports, in other species, are available which demonstrated the successful use of molecular marker for the development of tolerant cultivars against abiotic stresses [121]. As an illustration, the maintenance of potassium homeostasis in salt-tolerant plants was regulated by *SKC1*, which was mapped on chromosome 1 [122]. This molecular marker can be used for selecting salt-tolerant cultivars. Development of transgenic plants with improved resistance against heat, drought and salt stresses is also a possible approach as high throughput sequencing techniques help in exploring the expression of genes specific for abiotic stress tolerance [123].

The scope of breeding for the salinity, heat and drought is limited due to less selection efficiency, inadequate screening techniques, and the minimum understanding of the interaction between environment and stress. Now the molecular marker technology is helpful to develop the new maize cultivars with improved traits. However, the reasonable way at this stage is the improvement of transgenic maize with enhanced resistance against heat, drought and salt stresses. The high-throughput integrated approaches that are provided by the genomic technologies are helpful to examine the expression of the genes for all abiotic stresses including drought [2]. Microarray profiling under drought stress effects has been studied in different plant species i.e., *Arabidopsis* [124]. These studies recognized the multiple expressed transcripts of the genes which are involved in the photosynthesis, biosynthesis of osmoprotectants, ABA biosynthesis and signaling, water uptake, detoxification of reactive oxygen, and a myriad of transcription factors of various members of the zinc finger, protein stability and protection, bZIP and WRKY families (Table 2) [2].

Gene Family	Gene	Tolerance Mechanism	Reference
WRKY	<i>ZmWRKY33</i>	Overexpression of <i>ZmWRKY33</i> in Arabidopsis activated stress-induced genes, for example, <i>RD29A</i> , under normal growth condition and improved salt stress tolerance under stress condition.	[125]
	<i>WRKY25</i> and <i>WRKY33</i>	Upstream intergenic regions from each gene that were sufficient to confer stress-inducible expression on a reporter gene; W-box in their upstream regions also might be responsible to confer salt tolerance	[126]
MYB	<i>ZmMYB3R</i>	Overexpression of <i>ZmMYB3R</i> confer salt tolerance in transgenic plants	[127]
	<i>ZmMYB30</i>	Ectopic expression of <i>ZmMYB30</i> in transgenic Arabidopsis plants promoted salt-stress tolerance and also increased the expression of a number of abiotic stress-related genes, allowing the plants to overcome adverse conditions	[128]
AP2/ERF	<i>ZmEREB20</i>	Overexpression of <i>ZmEREB20</i> confer salt tolerance in transgenic plants	[129]
bZIP	<i>ZmbZIP72</i>	Overexpression of <i>ZmbZIP72</i> enhanced the expression of ABA-inducible genes such as <i>RD29B</i> , <i>RAB18</i> , and <i>HIS1-3</i> , which resulted in enhanced salinity tolerance	[130]
	<i>ZmbZIP60</i>	Overexpression of <i>ZmbZIP60</i> confer salt tolerance in transgenic plants	[131]
	<i>ZmbZIP4</i>	<i>ZmbZIP4</i> could positively regulate a number of stress response genes, such as <i>ZmLEA2</i> , <i>ZmRD20</i> , <i>ZmRD21</i> , <i>ZmRab18</i> , <i>ZmNHX3</i> , <i>ZmGEA6</i> , and <i>ZmERD</i> , and some abscisic acid synthesis-related genes, including <i>NCED</i> , <i>ABA1</i> , <i>AAO3</i> , and <i>LOS5</i> to enhance salinity tolerance	[132]

Table 2.
 Transcription factors mediated salinity tolerance in maize.

4. Conclusion

The changing climate scenario has worsened the salinity problem while global warming has caused significant increase in salt affected lands and thus has jeopardized the food security of millions of people across the globe. As a C4 plant, maize can moderately tolerate salinity; however, the initial growth stage of maize is highly sensitive to salinity stress. The adverse effect of salinity can be mitigated through understanding the adaptability of maize in saline environments. Several seed enhancement and genetic approaches can be adapted to overcome the adverse effects of salinity stress. Among them, biological enhancement through seed priming, application of antioxidants and growth hormones, genetic and molecular techniques for development of tolerant cultivars, and several agronomic management practices such as optimizing sowing time and seed rate etc. can be useful to cope with the adverse effect of salinity. Ultimately, these approaches have the potential to multiply maize production and nutritional quality in saline environments under current and future scenario of climate change.

Conflict of interest

The authors declare no conflict of interest.

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