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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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References

- [1] Munns R, Tester M. Mechanisms of salinity tolerance. *Annual Review of Plant Biology*. 2008;59:651-681.
- [2] Javed T, Shabbir R, Ali A, Afzal I, Zaheer U, Gao SJ. Transcription factors in plant stress responses: Challenges and potential for sugarcane improvement. *Plants*. 2020;9(4):491.
- [3] EL Sabagh A, Hossain A, Islam MS, Barutçular C, Ratnasekera D, Gormus O, Amanet K, Mubeen M, Nasim W, Fahad S, Tariq M. Drought and heat stress in cotton (*Gossypium hirsutum* L.): Consequences and their possible mitigation strategies. *Agronomic Crops*; 2020. p. 613-634.
- [4] Seleiman MF, Al-Suhaibani N, Ali N, Akmal M, Alotaibi M, Refay Y, Dindaroglu T, Abdul-Wajid HH, Battaglia ML. Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*. 2021a;10(2):259.
- [5] Daliakopoulos IN, Tsanis IK, Koutroulis A, Kourgialas NN, Varouchakis AE, Karatzas GP, Ritsema CJ. The threat of soil salinity: A European scale review. *Science of the Total Environment*. 2016;573:727-739.
- [6] McFarlane DJ, George RJ, Barrett-Lennard EG, Gilfedder M. Salinity in dryland agricultural systems: challenges and opportunities. In: *Innovations in dryland agriculture*. Springer: Cham; 2016 p. 521-547.
- [7] EL Sabagh A, Hossain A, Barutçular C, Iqbal MA, Islam MS, Fahad S, Sytar O, Çiğ F, Meena RS, Erman M. Consequences of salinity stress on the quality of crops and its mitigation strategies for sustainable crop production: an outlook of arid and semi-arid regions. In: *Environment, Climate, Plant and Vegetation Growth*. Springer: Cham; 2020a, p. 503-533.
- [8] Adnan M, Fahad S, Zamin M, Shah S, Mian IA, Danish S, Zafar-ul-Hye M, Battaglia ML, Naz RM, Saeed B, Saud S. Coupling phosphate-solubilizing bacteria with phosphorus supplements improve maize phosphorus acquisition and growth under lime induced salinity stress. *Plants*. 2020;9(7):900.
- [9] Seleiman MF, Almutairi KF, Alotaibi M, Shami A, Alhammad BA, Battaglia ML. Nano-fertilization as an emerging fertilization technique: why can modern agriculture benefit from its use?. *Plants*. 2021b;10(1):2.
- [10] EL Sabagh A, Hossain A, Barutçular C, Islam MS, Ratnasekera D, Kumar N, Meena RS, Gharib HS, Saneoka H, da Silva JA. Drought and salinity stress management for higher and sustainable canola (*Brassica napus* L.) production: A critical review. *Australian Journal of Crop Science*. 2019a;13(1):88-96.
- [11] EL Sabagh A, Hossain A, Islam MS, Barutçular C, Ratnasekera D, Kumar N, Meena RS, Gharib HS, Saneoka H, da Silva JA. Sustainable soybean production and abiotic stress management in saline environments: A critical review. *Australian Journal of Crop Science*. 2019b;13(2):228-236.
- [12] Farooq M, Hussain M, Wakeel A, Siddique KH. Salt stress in maize: effects, resistance mechanisms, and management. A review. *Agronomy for Sustainable Development*. 2015;35(2): 461-481.
- [13] Khaliq A, Iqbal MA, Zafar M, Gulzar A. Appraising economic dimension of maize production under coherent fertilization in Azad Kashmir, Pakistan. *Cust Agroneg*. 2019;15(2): 243-253.
- [14] Maqsood Q, N Abbas R, A Iqbal M, A Serap K, Iqbal A, EL Sabagh A.

Overviewing of weed management practices to reduce weed seed bank and to increase maize yield. *Planta Daninha*. 2020:38.

[15] Billah M, Latif MA, Hossain N, Shalim Uddin M. Evaluation and selection of salt tolerant hybrid maize under hydroponics culture. *Research on Crops*. 2017:18(3).

[16] Feng G, Zhang Z, Wan C, Lu P, Bakour A. Effects of saline water irrigation on soil salinity and yield of summer maize (*Zea mays* L.) in subsurface drainage system. *Agricultural Water Management*. 2017:193:205-213.

[17] Sumer AL, Zörb C, Yan F, Schubert S. Evidence of sodium toxicity for the vegetative growth of maize (*Zea mays* L.) during the first phase of salt stress. *Journal of Applied Botany*. 2004:78:135-139.

[18] Rahman S, Sarker MR, Mia MY. Spatial and temporal variation of soil and water salinity in the South-Western and South-Central Coastal Region of Bangladesh. *Irrigation and Drainage*. 2017:66(5):854-871.

[19] Parvin GA, Ali MH, Fujita K, Abedin MA, Habiba U, Shaw R. Land use change in southwestern coastal Bangladesh: Consequence to food and water supply. In: *Land Use Management in Disaster Risk Reduction*. Springer: Tokyo; 2017, p. 381-401.

[20] Borlu HO, Celiktaş V, Düzenli S, Hossain A, EL Sabagh A. Germination and early seedling growth of five durum wheat cultivars (*Triticum durum* desf.) is affected by different levels of salinity. *Fresenius Environmental Bulletin*. 2018:27(11):7746-7757.

[21] Taiz L. and Zeiger E. Plant physiology. *Annals of Botany*. 2003:91(6):750.

[22] Carpić EB, Celýk N, Bayram G. Effects of salt stress on germination of

some maize (*Zea mays* L.) cultivars. *African Journal of Biotechnology*. 2009:8(19).

[23] Ashraf M, Foolad MR. Pre-sowing seed treatment-A shotgun approach to improve germination, plant growth, and crop yield under saline and non-saline conditions. *Advances in agronomy*. 2005:88:223-271.

[24] Bojović B, Đelić G, Topuzović M, Stanković M. Effects of NaCl on seed germination in some species from families Brassicaceae and Solanaceae. *Kragujevac Journal of Science*. 2010:32:83-87.

[25] Goldsworthy. Calcium and salinity. *Applied Biology*. 1994:4:1-6.

[26] Khajeh-Hosseini M, Powell AA, Bingham IJ. The interaction between salinity stress and seed vigour during germination of soybean seeds. *Seed Science and Technology*. 2003:31(3): 715-725.

[27] Gama PB, Inanaga S, Tanaka K, Nakazawa R. Physiological response of common bean (*Phaseolus vulgaris* L.) seedlings to salinity stress. *African Journal of Biotechnology*. 2007:6(2).

[28] Diatta AA, Thomason WE, Abaye O, Thompson TL, Battaglia ML, Vaughan LJ, Lo M, Jose Filho FD. Assessment of nitrogen fixation by mungbean genotypes in different soil textures using 15 n natural abundance method. *Journal of Soil Science and Plant Nutrition*. 2020:0(4):2230-2240.

[29] Yohannes G, Abraha B. The role of seed priming in improving seed germination and seedling growth of maize (*Zea mays* L.) under salt stress at laboratory conditions. *African Journal of Biotechnology*. 2013:12(46):6484-6490.

[30] Farsiani A, Ghobadi ME. Effects of PEG and NaCl stress on two cultivars of corn (*Zea mays* L.) at germination and early seedling stages. *World Academy of*

Science, Engineering and Technology. 2009:57:382-385.

[31] Corwin DL. Climate change impacts on soil salinity in agricultural areas. European Journal of Soil Science. 2020.

[32] Cramer GR. Sodium-calcium interactions under salinity stress. In: Salinity: Environment-plants-Molecules. Springer: Dordrecht; 2002, p. 205-227.

[33] El Sayed HE. Influence of salinity stress on growth parameters, photosynthetic activity and cytological studies of *Zea mays*, L. plant using hydrogel polymer. Agriculture and Biology Journal of North America. 2011: 2(6):907-920.

[34] Shahzad M, Witzel K, Zörb C, Mühling KH. Growth-related changes in subcellular ion patterns in maize leaves (*Zea mays* L.) under salt stress. Journal of Agronomy and Crop Science. 2012: 198(1):46-56.

[35] Munns R. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. Plant, Cell and Environment. 1993:16(1):15-24.

[36] Agami RA. Alleviating the adverse effects of NaCl stress in maize seedlings by pretreating seeds with salicylic acid and 24-epibrassinolide. South African Journal of Botany. 2013:88:171-177.

[37] Akram M, Ashraf MY, Ahmad R, Rafiq M, Ahmad I, Iqbal J. Allometry and yield components of maize (*Zea mays* L.) hybrids to various potassium levels under saline conditions. Archives of Biological Sciences. 2010:62(4):1053-1061.

[38] Qu C, Liu C, Gong X, Li C, Hong M, Wang L, Hong F. Impairment of maize seedling photosynthesis caused by a combination of potassium deficiency and salt stress. Environmental and Experimental Botany. 2012:75:134-141.

[39] Schubert S, Neubert A, Schierholt A, Sümer A, Zörb C. Development of

salt-resistant maize hybrids: the combination of physiological strategies using conventional breeding methods. Plant Science. 2009:177(3):196-202.

[40] Kaya C, Tuna AL, Okant AM. Effect of foliar applied kinetin and indole acetic acid on maize plants grown under saline conditions. Turkish Journal of Agriculture and Forestry. 2010:34(6):529-538.

[41] Omoto E, Taniguchi M, Miyake H. Adaptation responses in C4 photosynthesis of maize under salinity. Journal of Plant Physiology. 2012:169(5): 469-477.

[42] Zörb C, Stracke B, Tramnitz B, Denter D, Sümer A, Mühling KH, Yan F, Schubert S. Does H⁺ pumping by plasmalemma ATPase limit leaf growth of maize (*Zea mays*) during the first phase of salt stress?. Journal of Plant Nutrition and Soil Science. 2005:168(4):550-557.

[43] Pitann B, Zörb C, Mühling KH. Comparative proteome analysis of maize (*Zea mays* L.) expansions under salinity. Journal of Plant Nutrition and Soil Science. 2009c:172:75-77.

[44] Hager A. Role of the plasma membrane H⁺-ATPase in auxin-induced elongation growth: historical and new aspects. Journal of Plant Research. 2003:116(6):483-505.

[45] Cosgrove DJ. Loosening of plant cell walls by expansins. Nature. 2000:407: 321-326.

[46] Uddin MN, Hanstein S, Leubner R, Schubert S. Leaf cell-wall components as influenced in the first phase of salt stress in three maize (*Zea mays* L.) hybrids differing in salt resistance. Journal of Agronomy and Crop Science. 2013:199(6):405-415.

[47] Pitann B, Kranz T, Mühling KH. The apoplastic pH and its significance in adaptation to salinity in maize (*Zea mays* L.): comparison of fluorescence

microscopy and pH-sensitive micro-electrodes. *Plant Science*. 2009a:176(4): 497-504.

[48] Pitann B, Schubert S, Mühling KH. Decline in leaf growth under salt stress is due to an inhibition of H⁺-pumping activity and increase in apoplastic pH of maize leaves. *Journal of Plant Nutrition and Soil Science*. 2009b:172(4):535-543.

[49] Wu Y, Meeley RB, Cosgrove DJ. Analysis and expression of the α -expansin and β -expansin gene families in maize. *Plant Physiology*. 2001:126(1):222-232.

[50] De Costa W, Zörb C, Hartung W, Schubert S. Salt resistance is determined by osmotic adjustment and abscisic acid in newly developed maize hybrids in the first phase of salt stress. *Physiologia Plantarum*. 2007:131(2):311-321.

[51] Geilfus CM, Zörb C, Mühling KH. Salt stress differentially affects growth-mediating β -expansins in resistant and sensitive maize (*Zea mays* L.). *Plant Physiology and Biochemistry*. 2010: 48(12):993-998.

[52] Encina A, Fry SC. Oxidative coupling of a feruloyl-arabinoxylan trisaccharide (FAXX) in the walls of living maize cells requires endogenous hydrogen peroxide and is controlled by a low-M_r apoplastic inhibitor. *Planta*. 2005:223(1):77-89.

[53] Lindsay SE, Fry SC. Control of diferulate formation in dicotyledonous and gramineous cell-suspension cultures. *Planta*. 2008:227(2):439-452.

[54] Burr SJ, Fry SC. Extracellular cross-linking of maize arabinoxylans by oxidation of feruloyl esters to form oligoferuloyl esters and ether-like bonds. *The Plant Journal*. 2009:58(4):554-567.

[55] Yassin M, Mekawy AM, EL Sabagh A, Islam MS, Hossain A, Barutcular C, Alharby H, Bamagoos A, Liu L, Ueda A, Saneoka H. Physiological

and biochemical responses of two bread wheat (*Triticum aestivum* L.) genotypes grown under salinity stress. *Applied Ecology and Environmental Research*. 2019:17(2):5029-5041

[56] Monsur MB, Ivy NA, Haque MM, Hasanuzzaman M, EL Sabagh A, Rohman MM. Oxidative stress tolerance mechanism in rice under salinity. *Phyton*. 2020:89(3):497.

[57] Liu L, Nakamura Y, Taliman NA, EL Sabagh A, Moghaieb RE, Saneoka H. differences in the growth and physiological responses of the leaves of *Peucedanum japonicum* and *Hordeum vulgare* exposed to salinity. *Agriculture*. 2020:10(8):317.

[58] De Souza IR, MacAdam JW. A transient increase in apoplastic peroxidase activity precedes decrease in elongation rate of B73 maize (*Zea mays*) leaf blades. *Physiologia Plantarum*. 1998:104(4):556-562.

[59] de Souza IR, MacAdam JW. Gibberellic acid and dwarfism effects on the growth dynamics of B73 maize (*Zea mays* L.) leaf blades: a transient increase in apoplastic peroxidase activity precedes cessation of cell elongation. *Journal of Experimental Botany*. 2001:52(361): 1673-1682.

[60] Devi SR, Prasad MN. Ferulic acid mediated changes in oxidative enzymes of maize seedlings: implications in growth. *Biologia Plantarum*. 1996:38(3):387.

[61] Mubeen M, Ahmad A, Wajid A, Khaliq T, Hammad HM, Sultana SR, Ahmad S, Fahad S, Nasim W. Application of CSM-CERES-Maize model in optimizing irrigated conditions. *Outlook on Agriculture*. 2016:45(3):173-184.

[62] Mubeen M, Bano A, Ali B, Islam ZU, Ahmad A, Hussain S, Fahad S, Nasim W. Effect of plant growth promoting bacteria and drought on spring maize. *Pakistan Journal of Botany*. 2021:53:2.

- [63] Battaglia ML, Lee C, Thomason W. Corn yield components and yield responses to defoliation at different row widths. *Agronomy Journal*. 2018;110(1): 210-225.
- [64] Battaglia M, Lee C, Thomason W, Fike J, Sadeghpour A. Hail damage impacts on corn productivity: A review. *Crop Science*. 2019b;59(1):1-4.
- [65] Kaya C, Ashraf M, Dikilitas M, Tuna AL. Alleviation of salt stress-induced adverse effects on maize plants by exogenous application of indoleacetic acid (IAA) and inorganic nutrients-A field trial. *Australian Journal of Crop Science*. 2013;7(2):249-254.
- [66] Katerji N, Van Hoorn JW, Hamdy A, Karam F, Mastrorilli M. Effect of salinity on water stress, growth, and yield of maize and sunflower. *Agricultural Water Management*. 1996;30(3):237-249.
- [67] Schubert S. Salt resistance of crop plants: physiological characterization of a multigenic trait. *The Molecular and Physiological Basis of Nutrient Use Efficiency in Crops*. 2011;13:443-455.
- [68] Hütsch BW, Saqib M, Osthusenrich T, Schubert S. Invertase activity limits grain yield of maize under salt stress. *Journal of Plant Nutrition and Soil Science*. 2014;177(2):278-286.
- [69] Farooq M, Hussain M, Siddique KH. Drought stress in wheat during flowering and grain-filling periods. *Critical Reviews in Plant Sciences*. 2014;33(4):331-349.
- [70] Hammad HM, Abbas F, Saeed S, Fahad S, Cerdà A, Farhad W, Bernardo CC, Nasim W, Mubeen M, Bakhat HF. Offsetting land degradation through nitrogen and water management during maize cultivation under arid conditions. *Land Degradation and Development*. 2018;29(5):1366-1375.
- [71] Gadalla AM, Hamdy A, Galal YG, Aziz HA, Mohamed MA. Evaluation of maize grown under salinity stress and N application strategies using stable nitrogen isotope. In: 8th African Crop Science Society Conference, El-Minia, Egypt, 27-31. African Crop Science Society. 2007. p. 1653-1662.
- [72] EL Sabagh A, Hossain A, Iqbal MA, Barutçular C, Islam MS, Çiğ F, Erman M, Sytar O, Brestic M, Wasaya A, Jabeen T. Maize Adaptability to Heat Stress under Changing Climate. In: *Plant Stress Physiology*. IntechOpen; 2020b.
- [73] Li J, Chen J, Jin J, Wang S, Du B. Effects of irrigation water salinity on maize (*Zea mays* L.) emergence, growth, yield, quality, and soil salt. *Water*. 2019;11(10):2095.
- [74] Weinberg ZG, Yan Y, Chen Y, Finkelman S, Ashbell G, Navarro S. The effect of moisture level on high-moisture maize (*Zea mays* L.) under hermetic storage conditions—in vitro studies. *Journal of Stored Products Research*. 2008;44(2):136-144.
- [75] Cucci G, Lacolla G, Boari F, Mastro MA, Cantore V. Effect of water salinity and irrigation regime on maize (*Zea mays* L.) cultivated on clay loam soil and irrigated by furrow in Southern Italy. *Agricultural Water Management*. 2019;222:118-24.
- [76] Serraj R, Sinclair TR. Osmolyte accumulation: can it really help increase crop yield under drought conditions?. *Plant, cell & environment*. 2002;25(2): 333-341.
- [77] Yancey PH. Compatible and counteracting solutes. *Cellular and molecular physiology of cell volume regulation*. 1994:81-109.
- [78] Sharma A, Shahzad B, Kumar V, Kohli SK, Sidhu GP, Bali AS, Handa N, Kapoor D, Bhardwaj R, Zheng B. Phytohormones regulate accumulation of osmolytes under abiotic stress. *Biomolecules*. 2019;9(7):285.

- [79] Ahmad P, Rasool S, Gul A, Sheikh SA, Akram NA, Ashraf M, Kazi AM, Gucel S. Jasmonates: multifunctional roles in stress tolerance. *Frontiers in Plant Science*. 2016;7:813.
- [80] Ahmad B, Zaid A, Sadiq Y, Bashir S, Wani SH. Role of selective exogenous elicitors in plant responses to abiotic stress tolerance. In: *Plant Abiotic Stress Tolerance*. Springer: Cham; 2019, p. 273-290.
- [81] Hasanuzzaman M, Nahar K, Bhuiyan TF, Anee TI, Inafuku M, Oku H, Fujita M. Salicylic acid: an all-rounder in regulating abiotic stress responses in plants. *Phytohormones-Signaling Mechanisms and Crosstalk in Plant Development and Stress Responses*. 2017;16:31-75.
- [82] Riffat A, Ahmad MS. Changes in organic and inorganic osmolytes of maize (*Zea mays* L.) by sulfur application under salt stress conditions. *The Journal of Agricultural Science*. 2018;10:543-561.
- [83] Akter N, Islam MR, Karim MA, Hossain T. Alleviation of drought stress in maize by exogenous application of gibberellic acid and cytokinin. *Journal of Crop Science and Biotechnology*. 2014;17(1):41-48.
- [84] Wang C, Yang A, Yin H, Zhang J. Influence of water stress on endogenous hormone contents and cell damage of maize seedlings. *Journal of Integrative Plant Biology*. 2008;50(4):427-434.
- [85] Shaddad MA, Abd El-Samad MH, Mohammed HT. Interactive effects of drought stress and phytohormones or polyamines on growth and yield of two M (*Zea mays* L.) genotypes. *American Journal of Plant Sciences*. 2011;2(06):790.
- [86] Adejumo SA, Awoyemi V, Togun AO. Exogenous proline and hormone in combination with compost improves growth and tolerance of maize under heavy metal stress. *Plants and Environment*. 2020;2(1):40-53.
- [87] Hayat Q, Hayat S, Irfan M, Ahmad A. Effect of exogenous salicylic acid under changing environment: a review. *Environmental and Experimental Botany*. 2010;68(1):14-25.
- [88] Elgamaal AA, Maswada HF. Response of three yellow maize hybrids to exogenous salicylic acid under two irrigation intervals. *Asian Journal of Crop Science*. 2013;5(3):264-274.
- [89] Saruhan N, Saglam A, Kadioglu A. Salicylic acid pretreatment induces drought tolerance and delays leaf rolling by inducing antioxidant systems in maize genotypes. *Acta Physiologiae Plantarum*. 2012;34(1):97-106.
- [90] Rao SR, Qayyum A, Razzaq A, Ahmad M, Mahmood I, Sher A. Role of foliar application of salicylic acid and L-tryptophan in drought tolerance of maize. *Journal of Animal and Plant Sciences*. 2012;22(3):768-772.
- [91] Ismail MA. Alleviation of salinity stress in white corn (*Zea mays* L.) plant by exogenous application of salicylic acid. *American Journal of Life Science*. 2013;1(6):248-255.
- [92] Khan W, Prithiviraj B, Smith DL. Photosynthetic responses of corn and soybean to foliar application of salicylates. *Journal of Plant Physiology*. 2003;160(5):485-492.
- [93] Khodary SE. Effect of salicylic acid on the growth, photosynthesis and carbohydrate metabolism in salt stressed maize plants. *International Journal of Agriculture and Biology*. 2004;6(1):5-8.
- [94] Fahad S, and Bano A. Effect of salicylic acid on physiological and biochemical characterization of maize grown in saline area. *Pakistan Journal of Botany*. 2012;44(4): 1433e1438.
- [95] Tufail A, Arfan M, Gurmani AR, Khan A, Bano A. Salicylic acid induced salinity tolerance in maize (*Zea mays*).

Pakistan Journal of Botany.
2013;45:75e82.

[96] Vazirimehr MR, Rigi K. Effect of salicylic acid in agriculture. International Journal of Plant, Animal and Environmental Sciences. 2014;4(2): 291-296.

[97] Wang J, Lv M, Islam F, Gill RA, Yang C, Ali B, Yan G, Zhou W. Salicylic acid mediates antioxidant defense system and ABA pathway related gene expression in *Oryza sativa* against quinclorac toxicity. Ecotoxicology and environmental safety. 2016;133:146-156.

[98] Santino A, Taurino M, De Domenico S, Bonsegna S, Poltronieri P, Pastor V. Jasmonate signalling in plant defense response to multiple abiotic stresses. Plant Cell Reports. 2013;32: 1085-1098.

[99] Shyu C, Brutnell TP. Growth–defence balance in grass biomass production: the role of jasmonates. Journal of Experimental Botany. 2015;66(14):4165-4176.

[100] Abdelgawad ZA, Khalafaallah AA, Abdallah MM. Impact of methyl jasmonate on antioxidant activity and some biochemical aspects of maize plant grown under water stress condition. Agricultural Sciences. 2014;5(12):1077.

[101] Tayyab N, Naz R, Yasmin H, Nosheen A, Keyani R, Sajjad M, Hassan MN, Roberts TH. Combined seed and foliar pre-treatments with exogenous methyl jasmonate and salicylic acid mitigate drought-induced stress in maize. PLoS ONE. 2020;15(5):e0232269.

[102] Basra SM, Farooq M, Khaliq A. Comparative study of pre-sowing seed enhancement treatments in fine rice (*Oryza sativa* L.). Pakistan Journal of Life and Social Sciences. 2003;1(1):21-25.

[103] Chartzoulakis K, Klapaki G. Response of two greenhouse pepper

hybrids to NaCl salinity during different growth stages. Scientia Horticulturae. 2000;86(3):247-260.

[104] Dodd GL, Donovan LA. Water potential and ionic effects on germination and seedling growth of two cold desert shrubs. American Journal of Botany. 1999;86(8):1146-1153.

[105] Iqbal MA. Cluster bean (*Cyamopsis tetragonoloba* L.) germination and seedling growth as influenced by seed invigoration techniques. American-Eurasian Journal of Agricultural and Environmental Sciences. 2015a;15(2): 197-204.

[106] Iqbal MA. Improving the growth and yield of Canola (*Brassica napus* L.) with seed treatment and foliar sprays of Brassica (*Brassica napus* L.) and moringa (*Moringa olifera* L.) leaf extracts. American-Eurasian Journal of Agricultural and Environmental Sciences. 2014;14(10):1067-1073.

[107] Javed T, Ali MM, Shabbir R, Anwar R, Afzal I, Mauro RP. Alleviation of Copper-Induced Stress in Pea (*Pisum sativum* L.) through Foliar Application of Gibberellic Acid. Biology. 2021;10(2):120.

[108] Javed T, Ali MM, Shabbir R, Gull S, Ali A, Khalid E, Abbas AN, Tariq M. Rice seedling establishment as influenced by cultivars and seed priming with potassium nitrate. Journal of Applied Research in Plant Sciences. 2020a;1(2):65-75.

[109] Moaaz Ali M, Javed T, Mauro RP, Shabbir R, Afzal I, Yousef AF. Effect of seed priming with potassium nitrate on the performance of tomato. Agriculture. 2020b;10(11):498.

[110] Roy NK, Srivastava AK. Adverse effect of salt-stress conditions on chlorophyll content in wheat (*Triticum aestivum*) leaves and its amelioration through pre-soaking treatments. Indian Journal of Agricultural Sciences. 2000;70(11):777-778.

- [111] Iqbal MA. Improving germination and seedling vigour of cowpea (*Vigna unguiculata* L.) with different priming techniques. American-Eurasian Journal of Agricultural and Environmental Sciences. 2015b;15:265-270.
- [112] Akter L, Fakir OA, Alam MK, Islam MU, Chakraborti P, Alam MJ, Rashid MH, Begum M, Kader MA. Amelioration of salinity stress in maize seed germination and seedling growth attributes through seed priming. Open Journal of Soil Science. 2018;8(05):137.
- [113] Foti R, Abureni K, Tigere A, Gotosa J, Gere J. The efficacy of different seed priming osmotica on the establishment of maize (*Zea mays* L.) caryopses. Journal of Arid Environments. 2008;72(6):1127-1130.
- [114] Čanak P, Mirosavljević M, Ćirić M, Vujošević B, Kešelj J, Stanisavljević D, Mitrović B. Seed priming as a method for improving maize seed germination parameters at low temperatures. Ratarstvo I Povrtarstvo. 2016;53(3):106-110.
- [115] Ghafari H, Razmjoo J. Effect of foliar application of nano-iron oxidase, iron chelate and iron sulphate rates on yield and quality of wheat. International Journal of Agronomy and Plant Production. 2013;4(11):2997-3003.
- [116] Bakht J, Shafik M, Jamal Y, Sher H. Response of maize (*Zea mays* L.) to seed priming with NaCl and salinity stress. Spanish Journal of Agricultural Research. 2011(1):252-61.
- [117] Ashraf M, Rauf H. Inducing salt tolerance in maize (*Zea mays* L.) through seed priming with chloride salts: Growth and ion transport at early growth stages. Acta Physiologiae Plantarum. 2001;23(4):407-414.
- [118] Imran M, Garbe-Schönberg D, Neumann G, Boelt B, Mühling KH. Zinc distribution and localization in primed maize seeds and its translocation during early seedling development. Environmental and Experimental Botany. 2017;143:91-98.
- [119] Imran M, Boelt B, Mühling KH. Zinc seed priming improves salt resistance in maize. Journal of Agronomy and Crop Science. 2018;204(4):390-399.
- [120] Yang X, Lu C. Photosynthesis is improved by exogenous glycinebetaine in salt-stressed maize plants. Physiologia Plantarum. 2005;124(3):343-352.
- [121] Das G, Patra JK, Baek KH. Insight into MAS: a molecular tool for development of stress resistant and quality of rice through gene stacking. Frontiers in Plant Science. 2017;8:985.
- [122] Das G, Rao GJ. Molecular marker assisted gene stacking for biotic and abiotic stress resistance genes in an elite rice cultivar. Frontiers in Plant Science. 2015;6:698.
- [123] Nguyen HC, Lin KH, Ho SL, Chiang CM, Yang CM. Enhancing the abiotic stress tolerance of plants: from chemical treatment to biotechnological approaches. Physiologia Plantarum. 2018;164(4):452-466.
- [124] Kawaguchi R, Girke T, Bray EA, Bailey-Serres J. Differential mRNA translation contributes to gene regulation under non-stress and dehydration stress conditions in *Arabidopsis thaliana*. The Plant Journal. 2004;38(5):823-839.
- [125] Li H, Gao Y, Xu H, Dai Y, Deng D, Chen J. *ZmWRKY33*, a WRKY maize transcription factor conferring enhanced salt stress tolerances in *Arabidopsis*. Plant Growth Regulation. 2013;70(3):207-216.
- [126] Jiang Y, Deyholos MK. Functional characterization of *Arabidopsis* NaCl-inducible WRKY25 and WRKY33 transcription factors in abiotic stresses.

Plant Molecular Biology. 2009 Jan 1;69(1-2):91-105.

[127] Wu J, Jiang Y, Liang Y, Chen L, Chen W, Cheng B. Expression of the maize MYB transcription factor ZmMYB3R enhances drought and salt stress tolerance in transgenic plants. *Plant physiology and biochemistry*. 2019 Apr 1;137:179-188.

[128] Chen YH, Cao YY, Wang LJ, Li LM, Yang J, Zou MX. Identification of MYB transcription factor genes and their expression during abiotic stresses in maize. *Biologia plantarum*. 2018 Jun;62(2):222-230.

[129] Fu J, Zhu C, Wang C, Liu L, Shen Q, Xu D, Wang Q. Maize transcription factor ZmEREB20 enhanced salt tolerance in transgenic *Arabidopsis*. *Plant Physiology and Biochemistry*. 2021 Feb 1;159:257-267.

[130] Ying S, Zhang DF, Fu J, Shi YS, Song YC, Wang TY, Li Y. Cloning and characterization of a maize bZIP transcription factor, ZmbZIP72, confers drought and salt tolerance in transgenic *Arabidopsis*. *Planta*. 2012 Feb;235(2):253-266.

[131] Wang B, Zheng J, Liu Y, Wang J, Wang G. Cloning and characterization of the stress-induced bZIP gene ZmbZIP60 from maize. *Molecular biology reports*. 2012 May 1;39(5):6319-6327.

[132] Ma H, Liu C, Li Z, Ran Q, Xie G, Wang B, Fang S, Chu J, Zhang J. ZmbZIP4 contributes to stress resistance in maize by regulating ABA synthesis and root development. *Plant physiology*. 2018 Oct 1;178(2):753-770.