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SALINITY INDUCED CHANGES IN GROWTH AND PHYSIOLOGY OF FIELD CROPS

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ABSTRACT

Salinity is one of the major threats to crop production. It hampers plant growth and development by causing mostly disturbance in water uptake, Na^+ and Cl^- toxicity, and imbalance in mineral ions in plant cell. Several physiological changes occur as a consequence, such as over production of reactive oxygen substances like peroxide, higher accumulation of toxic ions like Na^+, Cl^- and SO_4^{2-}, lowering of absorption of nutrients like K+, Ca^{2+}, Mg^{2+} and P, and decrease in xylem water potential. Seed germination, growth and finally yield of crops are affected. The relatively tolerant crops/varieties of a crop exhibit some physiological tolerance mechanisms like production of antioxidants, various types of protein such as proline, osmoprotectants and phytohormones to combat salt stress effect. Antioxidant enzymes like peroxidase activity increases to defend salt stress, however depending on the cultivars. In this review paper, the effects of salinity on the changes in growth and physiology of different field crops are discussed. The paper also focused on some defensive responses of field crops that adopted to continue their growth under salt stress.

Keywords: Physiological mechanisms, mineral ions, salt stress

Introduction

Salinity is one of the major abiotic stresses that cause significant loss of agricultural production. About 900 million ha of land in the world is under salinity, which is almost 20% of the land area of the world and 50% of the total irrigated arable land (Velmurugan *et al.* 2020). The major causes of soil salinity are weathering of rocks that contain soluble salt, natural calamities like cyclone, capillary movement of salt and/or irrigation with low quality water (Rengasamy 2006). Intrusion of seawater to the fresh river water during dry season, seepage of salty water due to dryness of the soil, rising of salt due to capillary movement and inundation of land due to cyclones are also some major natural causes of increasing soil salinity (Rahman *et al.* 2017, Karim 2015, Mondal *et al*. 2013).

The major staple food of the world comes from a small group of glycophytes, which are sensitive to salinity and unable to complete their life cycle when soil NaCl concentrations exceed 200 mM (Flowers *et al*. 2015, Munns and Tester 2008). Therefore, it is important to improve or develop crop varieties suitable for such salt affected area to meet global food security. To achieve the goal, it is necessary to understand clearly how the soil salinity affects various morphological, physiological, biochemical, metabolic and other processes of plants.

Salinity reduces seed germination, plant growth, development, and yield of field crops (Khan *et al*. 2013, Khan *et al.* 2014, Zhang and Dai 2019). It affects plant growth in three different ways, like creating osmotic stress, ion stress or ionic imbalance, and oxidative stress (Flowers 2004, Karim *et al.* 2012). Soil salinity disturbs plant water relation and creates osmotic stress by lowering soil as well as leaf water potential that reduces the turgidity of plant cells (Navada *et al*. 2020). Moreover, salinity affects gaseous exchange, photosynthetic machinery, and nutrient transportation which leads to lower yield of field crops. It also decreases the pigments of chlorophyll like chlorophyll a, chlorophyll b and carotenoids, distorts chloroplast and PSII system, and reduces stomatal conductance (Pan *et al.* 2021).

Crops when grown in saline soil take up salt from the soil, and the excess salt creates ion toxicity. Ion toxicity disturbs mineral nutrients uptake and ion homeostasis. Accumulation of excessive Na^+ and Cl^- ions inhibits the uptake of many other mineral nutrients from the soil like

K^+ and Ca^{2+} which results in ionic imbalance (Isayenkov and Maathuis 2019). Nonetheless, salinity enhances reactive oxygen species (ROS) production in plant cells which creates oxidative damages. The excess amount of ROS causes lipid peroxidation, membrane deterioration, as well as DNA and protein damage (Ghazali 2020). However, the plant adopts various strategies and approaches to maintain ion homeostasis, transport of ions and compartmentalization of the toxic ions, especially in vacuole. The strategies involve osmotic adaptation, biosynthesis of polyamines and stimulation of antioxidant machinery; and the approaches help in scavenging ROS and stabilizing membrane, mineral uptake and ion distribution (de Freitas *et al.* 2019).

There are many discoveries on understanding the salt tolerance strategy adopted by crop plant, but little progress is made in developing salt tolerant crop varieties. This implies that more information are necessary to understand clearly the salinity induced changes in growth pattern, physiological and biochemical parameters that are associated with salinity tolerance. In this review paper, we discussed the morpho-physiological strategy of crop plants that is taken to protect themselves from the harmful effect of salinity.

Relatives growths parameters: Seed is exposed to salinity soon after placed for germination, which is the first phase of crop life cycle. Salinity inhibits the imbibition process of seed germination by reducing the osmotic potential of the growth media. Salinity also creates toxic environment which changes many physiological and biochemical activities inside the seed during germination process. For example, salinity inhibits the activities of enzymes of protein and nucleic acid metabolism (Gomes-Filho *et al*. 2008) and disturbs the utilization of seed reserves (Othman *et al*. 2006). The rate and speed of seed germination vary with the species and varieties as well as with the salinity levels, e.g. in mustard (Bybordi 2010), maize (Khodarahmpour *et al*. 2012), and rice (Xu *et al.* 2011, Jamil *et al.* 2012). Salinity also reduces plant height significantly of many field crops, such as rice (Khanam *et al.* 2018), wheat (Akbarimoghaddam *et al.* 2011), soybean (Khan *et al.* 2013, Mannan *et al.* 2012). Salinity reduces both the length and dry weight of roots at various degrees as reported in rice (Hakim *et al*. 2014), wheat (Akbarimoghaddam *et al*. 2011), maize (Khodarahmpour *et al*. 2012), barley (Shelden *et al*. 2013), soybean (Karim *et al.* 2012; Mannan *et al.* 2012) and many other crops. It was also evident from Table 1 that the effects of salinity on different plant growth parameters were well correlated in 170 soybean genotypes (Mannan *et al.* 2012).

The salt stress ultimately affects yield contributing characters and yield in almost all the crops. Usually grain number in cereals and pods number of non-cereals are decreased by salinity. Individual seed weight however decreases when the salt concentration is relatively high (Mannan *et al.* 2013, Khanom *et al*. 2018). Such relationship between grain yield and salinity in soybean is shown in Figure 1 (Khan *et al.* 2016).

Genotypic variation in grain yield due to salinity exists in almost all the cultivated crops, and the variation is largely depended on the extent of damage on yield contributing characters. Besides these growth related parameters, salinity also significantly affects number of leaves per

Table 1. Correlation coefficient (Pearson's) between the relative growth parameters of 170 soybean genotypes subjected to salinity

Characters evaluated	Relative plant height	Relative stem dry weight	Relative leaf dry weight	Relative petiole dry weight	Relative root dry weight	Relative root:shoot ratio	Relative total dry weight
Relative shoot dry weight	0.622**	0.861**	0.941**	0.814**	0.496**	-0.650**	0.994**
Relative plant height	-	0.645**	0.535**	0.595**	0.454**	-0.272**	0.633**
Relative stem dry weight		-	0.698**	0.732**	0.532**	-0.485**	0.870**
Relative leaf dry weight			-	0.701**	0.449**	-0.621**	0.934**
Relative petiole dry weight				-	0.425**	-0.515**	0.811**
Relative root dry weight					-	0.258**	0.580**
Relative root: shoot ratio						-	-0.583**
Relative total dry weight							-

**Correlation is significant at the p = 0.01 level (2-tailed). (Mannan *et al.* 2012).

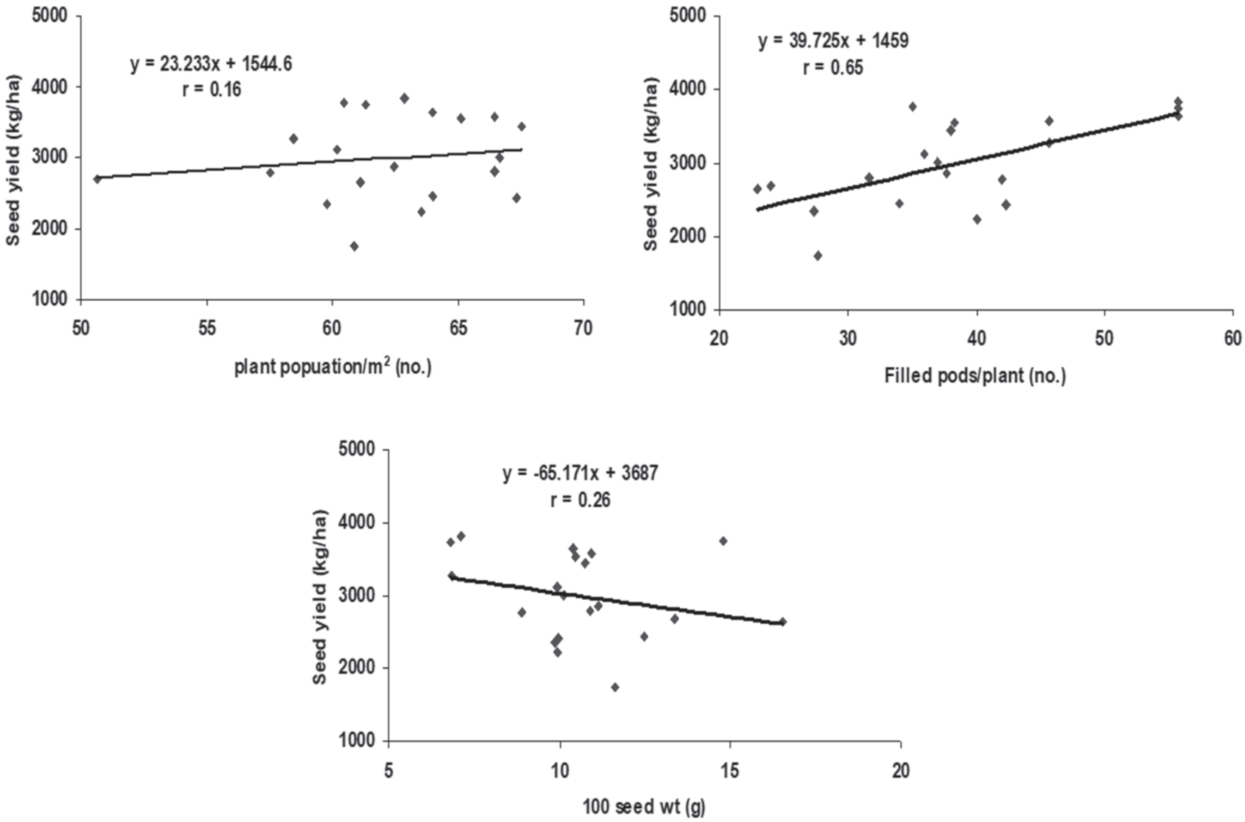

Figure 1. Relationship between yield contributing characters and seed yield of soybean (Khan *et al* 2016).

plant, leaf area index, number of panicles per plant, number of filled grains, leaf area duration and other plant attributes (Efisue *et al*. 2020, Mtilimbanya *et al.* 2020, Sade *et al*. 2018).

Water relation: Salinity affects xylem water potential by reducing soil water osmotic potential. Water potential determines the water status of the plants (Karim *et al*. 2012). Salinity forces the plant to accumulate higher amount of toxic ions (Na^+) which leads to a decrease in leaf water potential and turgor pressure (Methenni *et al*. 2018), and as a consequence leaves show water deficiency (Betzen *et al*. 2019), which is sometimes called physiological drought. Usually salt sensitive genotype shows lower leaf water potential than tolerant ones as shown in Figure 2. As salinity reduces the leaf water potential, many compatible solutes including K^+ are synthesized to maintain the turgor. However, the stomatal aperture may be partially or completely closed that reduces transpiration vis a vis results in the production of reactive oxygen species (ROS) and enhanced senescence.

Ion toxicity and nutritional balance: An ionic balance in plant cells is indispensable for maintaining the physiological processes and growth of plants. The presence of excess amount of salt in the soil solution hinders the uptake of mineral nutrients from the soil. Salinity creates specific ion toxicity to plants. The toxic ions in salt-affected soils are mainly sodium (Na^+), chloride (Cl^-), and sulfate (SO_4^{2-}) (Munns and Tester 2008). These ions also hinder the uptake of essential nutrients like P, K^+, N, and Ca (Zhu 2001). Nonetheless high Na^+ concentration reduces the uptake of K^+ and Ca^{2+} that ultimately reduces photosynthesis, as because potassium is an essential element for stomatal opening and closing (Tavakkoli *et al*. 2011). High Cl^- concentration also reduces the photosynthetic capacity of leaves by degrading chlorophyll.

In soybean, the amount of potassium reduced when the amount of sodium and chlorine increased with the increase of salinity (Mannan *et al.* 2013), and similar was also evident in the leaves and roots of safflower Kaya

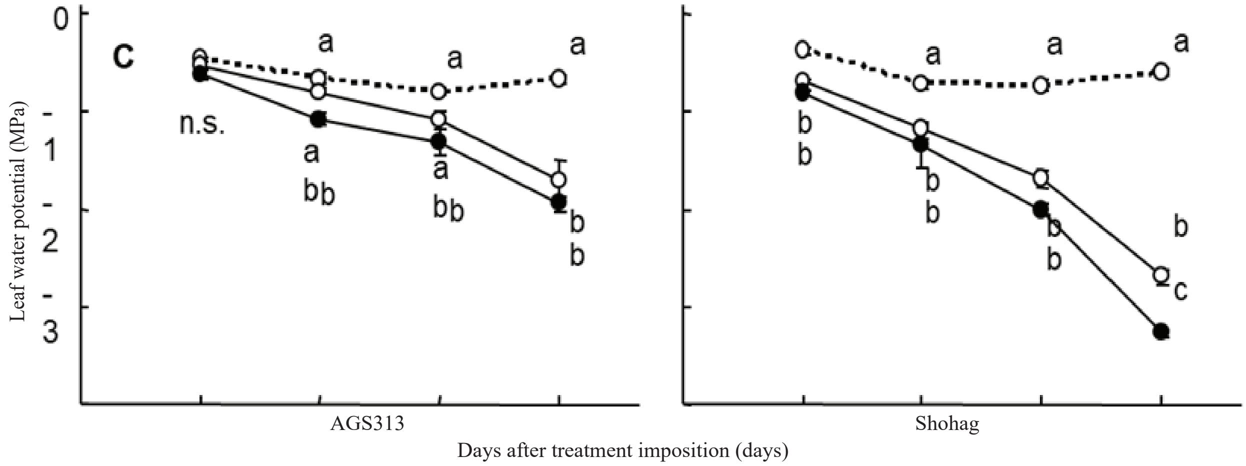

Figure 2. Effect of salinity on leaf water potential of a salt-tolerant (AGS 313) and salt-sensitive (Shohag) soybean genotypes (Mannan *et al*. 2013).

et al. (2011). The findings shown in Figure 3 disclosed that the Na^+ accumulation was compartmentalized in different plant parts, as in maize seedling the highest Na^+ accumulation was in roots (+404%), followed by in older leaves (+208%) and then young leaves (+137.3%), when K^+ accumulation reduced with the increase of the salt stress (Abd Elgawad *et al*. 2016).

Specific ion toxicity causes nutritional imbalance in plants. This may happen for several reasons, such as salinity may hinder some nutrients to be available for plants, create competition in the uptake between Na^+ and other essential nutrients, restrict transport or distribution of nutrients within the plant. The availability of micronutrients depends on the solubility of that nutrients, redox potential and pH of soil and availability of the natural binding sites in the soil. Salinity changes the favorable soil condition for nutrient availability, and micronutrient deficiencies are very common under salt stress. In chickpea, salinity affected survival and proliferation of *Rhizobium*. As a result, the nodulation process was hampered and nitrogen fixation was lowered (Ogutcu *et al.* 2009). In rice, Hakim *et al*. (2014) determined the concentration of different nutrient elements and found that most of the nutrients accumulation reduced except Na^+ that was increased in both root and shoot, and P also increased in roots though decreased in shoot (Table 2).

Photosynthesis: There is a strong negative relationship between the rate of photosynthesis and salinity concentrations in the root media. It was disclosed that at 50 mM NaCl photosynthesis was not affected in soybean though affected greatly at 100 mM NaCl (Karim *et al.* 2012). The affected photosynthesis was mainly due to

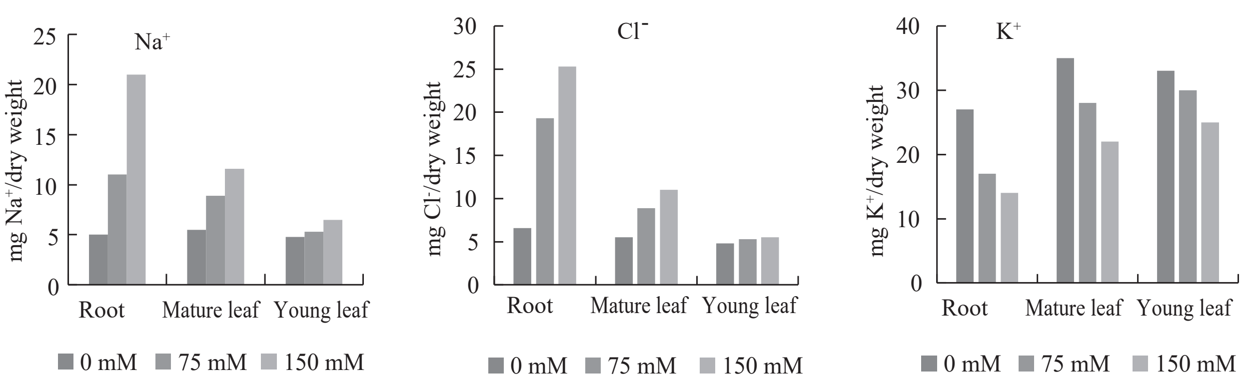

Figure 3. Amount of Na^+, Cl^- and K^+ as influenced by different levels of salinity in root, mature leaf and young leaf of 3 weeks old maize seedling (AbdElgawad *et al*. 2016).

Table 2. The effect of salinity on the accumulation of mineral nutrients of eight rice varieties

Salinity level (dS/m)	Nitrogen		Phosphorus		Sodium		potassium		Calcium		Magnesium	
	S	R	S	R	S	R	S	R	S	R	S	R
0	2.2	1.2	0.5	0.1	0.5	0.7	2.7	0.8	0.8	0.6	0.6	0.4
4	2.0	1.1	0.4	0.1	1.4	2.3	2.3	0.5	0.7	0.5	0.5	0.3
8	1.9	1.1	0.3	0.2	2.5	3.6	1.9	0.4	0.6	0.4	0.4	0.2
12	2.1	0.9	0.2	0.3	3.7	4.4	1.3	0.3	0.4	0.3	0.3	0.1

S= nutrients accumulated in shoot, R= Nutrients accumulated in root. The data is measured in percent nutrient compared to dry weight. (Hakim *et al*. 2014).

reduced stomatal conductance. The maximal quantum efficiency of PSII photochemistry, Fv/Fm was not changed even at 100 mM NaCl, and that suggested that photosynthesis under salinity was not affected due to damage in photosystem II rather due to stomatal factor (Karim *et al.* 2012). However, under extreme conditions salinity may damage photosynthetic processes such as photosystem I and II, and electron transport chain (Sudhir *et al*. 2005). A supporting finding was reported by Kalaji *et al*. (2011) that growth of barley was reduced by salinity by altering the chlorophyll fluorescence (PSII) as well as by enhancing the activity of oxygen evolving complex, and similar was also happened in *Brassica juncea* (Mittal *et al*. 2012).

Salinity also reduces the amount of photosynthetic pigments like chlorophyll a, chlorophyll b and other pigments which is another cause of reduction of photosynthesis as mentioned by Qados (2011). Saha *et al*. (2010) observed that salinity decreased the total amount of pigments of chlorophyll and not only the chlorophyll a, chlorophyll b, but also the carotenoids and xanthophylls in *Vigna radiata* at different degrees (Table 3). Farooq *et al*. (2015) disclosed that salinity lowers the leaf development and expansion, and causes early leaf abscission that is also responsible for lowering the photosynthesis. The prolonged salt stress causes ion toxicity, stomatal closure and membrane disruption that can be identified as the factors responsible for photosynthetic inhibition. A schematic diagram of Farooq *et al*. (2015) is given in Figure 4 that may explain the way of salinity induced ROS production that affects photosynthesis.

Oxidative stress: Salt stress disrupts the balance between production of reactive oxygen species (ROS) and antioxidant defense system. As a result, the amount of

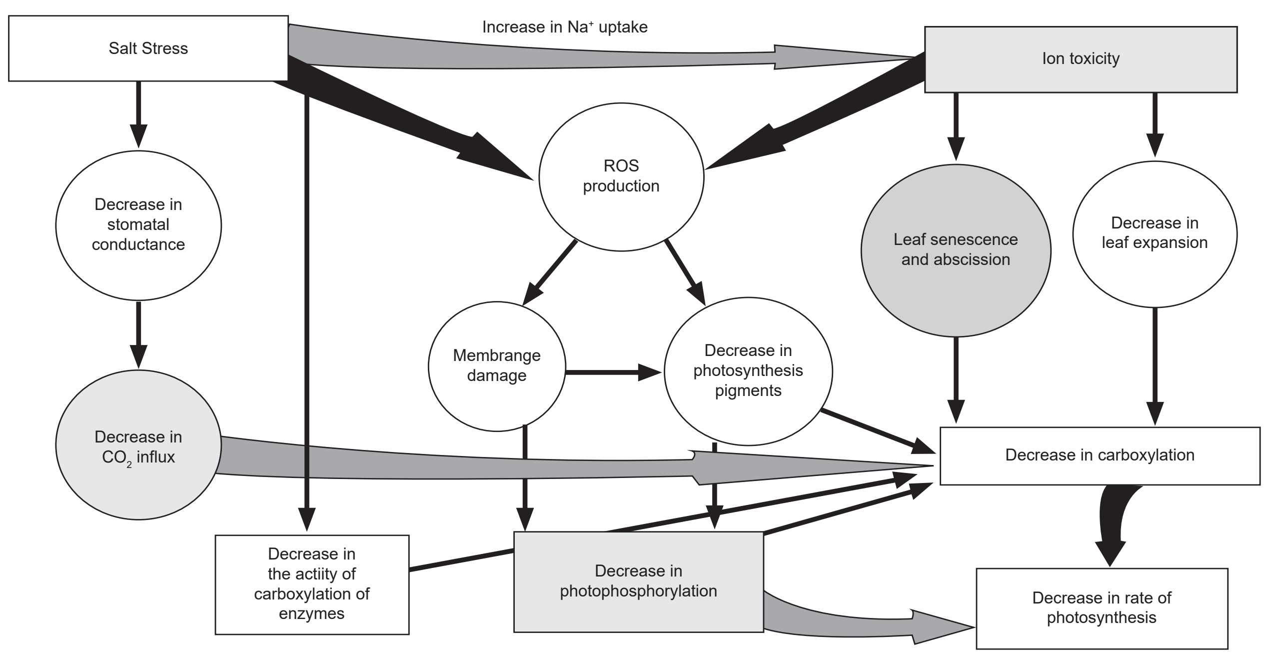

Figure 4. Influence of salt stress on photosynthesis. (Farooq *et al*. 2015).

Table 3. Effect of sodium chloride (NaCl) on photosynthetic pigments in seven days old mungbean seedlings

Treatment mM NaCl	Total Chl [mg g $^{-1}$(fw)]	Chl-a [mg g $^{-1}$(fw)]	Chl-b [mg g $^{-1}$(fw)]	Carotene [A_{425} g^{-1} (fw)]	Xanthophyll [A_{450} g $^{-1}$ (fw)]
0	0.8	0.5	0.3	1.1	1.2
50	0.7 (-9.8)	0.5 (-4.6)	0.2 (-18.5)	1.1 (-6.1)	1.1 (-5.3)
100	0.6 (-23.0)	0.4 (-12.1)	0.2 (-41.2)	1.0 (-12.8)	1.1 (-12.9)
150	0.3 (-60.4)	0.2 (-49.9)	0.1 (-77.8)	0.9 (-23.6)	0.7 (-38.8)

Here, fw = fresh weight. Figures in the parenthesis are % increase (+) or decrease (-) over control. (Saha *et al.* 2010).

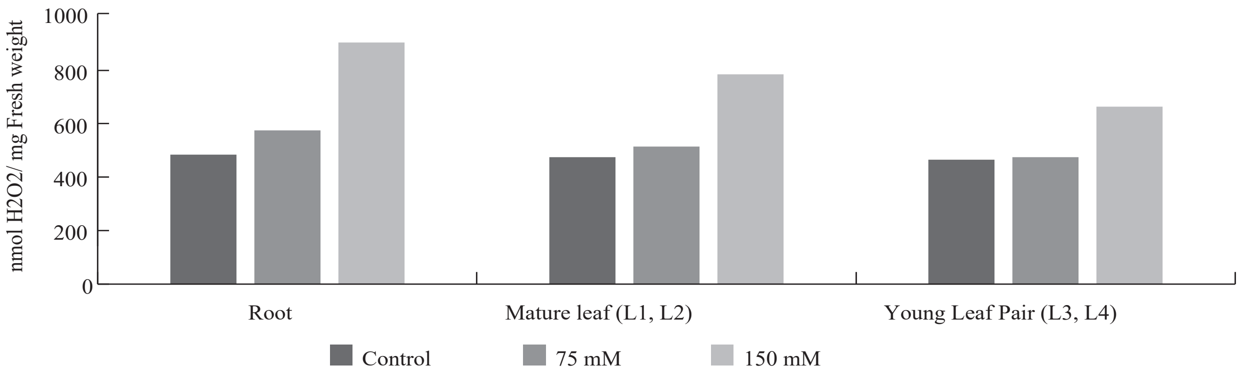

Figure 5. H_2O_2 production in root, mature leaves and young leaves of 3 weeks old maize seedlings. (AbdElgawad *et al*. 2016).

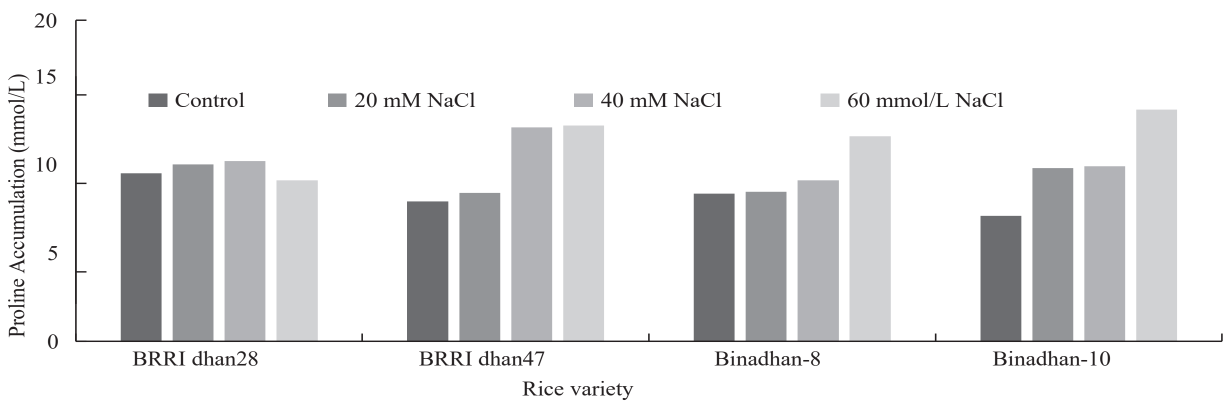

Figure 6. Effect of salinity levels on proline accumulation in four rice (Kibria *et al*. 2017).

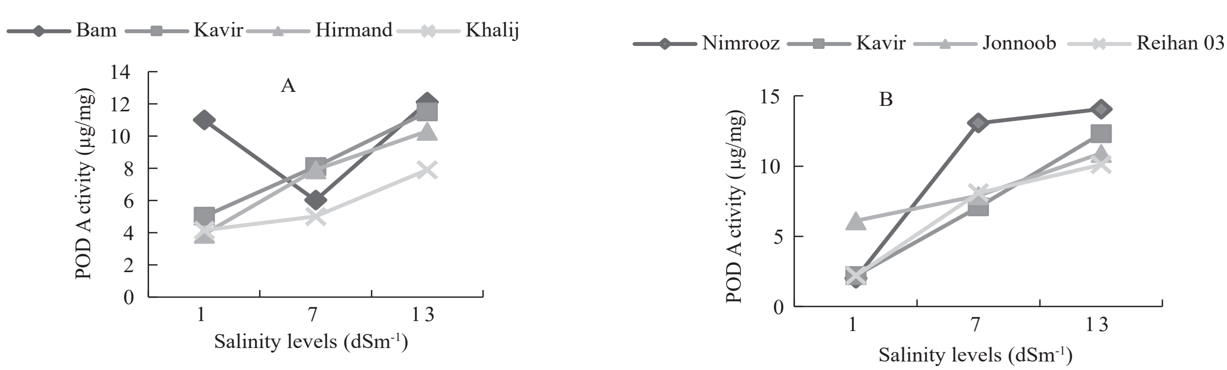

Figure 7. Effect of salinity stress on POD activity of (A) wheat and (B) barley cultivars (Izadi *et al*. 2014)

ROS accumulation increases and induces oxidative stress. The excessive amount of reactive oxygen species (ROS) can cause oxidation of protein, DNA damage, inactivation of enzymes and react with other vital component of cells. The decreased stomatal opening due to lower uptake of water under salt stress causes the chloroplast to expose to excited energy that generate ROS, such as superoxide ($O_2\bullet^-$), hydrogen peroxide (H_2O_2), hydroxyl radical (OH•), and singlet oxygen ($1O_2^-$) as reported by Parida and Das (2005), Ahmad *et al*. (2010, 2011). As shown in Figure 5 salinity increased H_2O_2 in roots and leaves of maize (AbdElgawad *et al*. 2016), and similarly increased lipid peroxidase and H_2O_2 in wheat seedling (Sairam *et al.* 2002, Hasanuzzaman and Fujita 2011b).

Proline accumulation: Plant synthesizes different osmotica in the form of sugars and organic compounds for osmotic adjustment of lowering leaf water potential under saline conditions. Proline, an amino acid, helps in osmotic adjustment (Gharsallah *et al*. 2016). An example of increased proline content due to salinity in rice can be found in Figure 6, where the salt-sensitive variety, BRRI dhan28 showed decreased amount of proline at 60 mmol/L NaCl, while salt tolerant Binadhan-10 accumulated the highest amount. BRRI dhan47 and Binadhan-8 also accumulated proline in response to salinity (Kibria *et al.* 2017).

Peroxidase activity: Peroxidase (POD) is an antioxidant enzyme that provides defensive action against salinity stress, and usually POD activity increases under salinity. In the study of Izadi *et al.* (2014) POD activity was increased with the increasing of salinity stress at all levels in four different wheat and barley cultivars, though cultivar difference in the activities was evident (Figure 7). They found that enzyme activity was the highest at 13 dSm^{-1} salinity for the wheat cultivar Bam and for the barley cultivar Nimrooz. The wheat cultivar Kavir showed the constant increase of POD activity with the increase of saline concentration. Besides these plant also produces other antioxidant enzymes like SOD (super oxide dismutase) or CAT (catalase) and non-enzymatic antioxidants like glutathione (GSH), ascorbate (ASC) which also act as defense mechanism against the detrimental effects of salinity (Mbarki *et al*. 2018).

Conclusion

Based on the recent understanding it is concluded that salinity affects growth and yield of crop plants by creating low water uptake, mineral toxicity and imbalance in mineral nutrition. As a consequence of low water in leaves, the stomatal resistance increases or even the stomata may close, and photosynthesis becomes slow. However non-stomatal limitation of photosynthesis is not usually occurred except under extreme saline condition. Furthermore, the stomatal closure leads to the production of ROS which denatures protein, photosynthetic machineries and reduces photosynthesis rate. However, the plant adopt some salinity tolerance strategies by accumulating different antioxidants enzymes, non-enzymatic compound, protein and hormonal secretion.

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