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Rational approaches - salicylic acid for salinity stress tolerance in plant

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Abstract
Salinity is a major menace for successful cultivation of agricultural crops causing inhibition and destruction of growth and development. High salinity affects plants in several ways viz; water stress, ion toxicity, nutritional disorders, oxidative stress and alteration of metabolic processes. Salinity reduces the agricultural productivity by hampering morpho-physiological and biochemical traits such as photosynthetic pigments, protein, proline, total soluble sugar and antioxidant enzymes activity. In view of mitigating salinity stress problem certain plant growth regulators were screened through exogenous applications on different crops. Out of them, one of the plant growth regulator salicylic acid (SA) has been found to have an effective role in salinity stress tolerance.

Keywords: Salinity, membrane stability index (MSI), photosynthetic pigments, proline, antioxidant enzymes and salicylic acid (SA)

Introduction
Plant growth and productivity are affected by nature's range as a number of abiotic stress factors. Soil salinity is a serious problem in worldwide agriculture areas because it limits plant growth and productivity. High salinity stress is the most severe environmental stress causing considerable losses to the crop production. High salinity interferes with plant growth and development and can also lead to physiological drought conditions and ion toxicity (Zhu, 2002) [141]. Therefore, high salinity affect mostly all aspects of plant physiology and metabolism and cause both hyper osmotic and hyper ionic stresses, which lead to plant demise. High salt deposition in soil leads to a deposition of a low water potential zone in the soil. This makes it increasingly difficult for the plant to acquire water as well as nutrients. Salinity causes ion-specific stresses resulting in an altered K^{+}/Na+ ratio. The external Na^+ can negatively impact intracellular K+ influx and salinity leads to a buildup of Na^+ and Cl^- concentrations in the cytosol, which can be ultimately detrimental to the cell. The Na^+ can dissipate the membrane potential and therefore facilitates the uptake of Cl^- down the gradient. Higher concentrations of sodium ions (above 100 mM) are toxic to cell metabolism and can inhibit the activity of many essential enzymes, cell division and expansion, membrane disorganization, and osmotic imbalance, which finally can lead to growth inhibition. Higher concentrations of sodium ions can also lead to a reduction in photosynthesis and the production of reactive oxygen species. Potassium ions are one of the essential elements required for growth and alterations in K+ ions disturb the osmotic balance, the function of stomata and the function of some enzymes. High salinity can also injure cells in transpiring leaves, which leads to growth inhibition. This salt-specific or ion-excess effect of salinity causes a toxic effect of salt inside the plant. The salt can concentrate in the old leaves and the leaves die, which is crucial for the survival of a plant (Munns *et al.*, 2006) [88].

Salinity stress can lead to stomatal closure, which reduces CO_2 availability in the leaves and inhibits carbon fixation, exposing chloroplasts to excessive excitation energy which in turn increase the generation of reactive oxygen species (ROS) such as superoxide, hydrogen peroxide, hydroxyl radical and singlet oxygen (Parida and Das, 2005; Ahmad *et al.*, 2010a, 2011) [98, 3]. In many plant studies, it was observed that production of ROS is increased under saline conditions (Hasegawa *et al.*, 2000) [46] and ROS-mediated membrane damage has been demonstrated to be a major cause of the cellular toxicity by salinity in different crop plants such as rice, tomato, citrus, pea and mustard (Gueta-Dahan *et al.*, 1997; Dionisio-Sese and Tobita, 1998; Mittova *et al.*, 2004; Ahmad *et al.*, 2009, 2010b) [43, 26, 84, 5, 4].

Many morpho-physiological, biochemical and molecular studies have revealed the deleterious effect of salinity stress on plants.

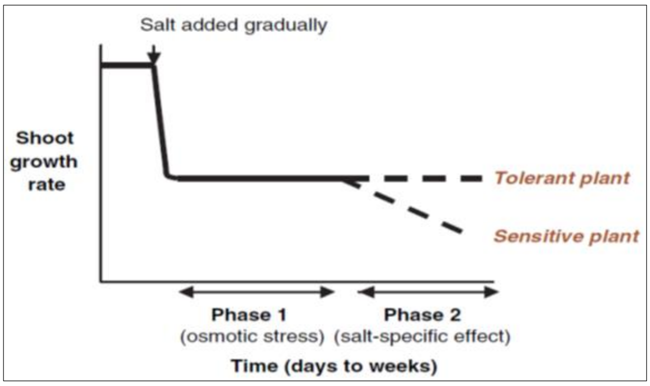
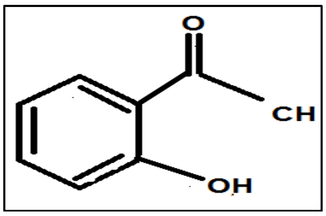


Fig 1: Schematic illustration of the two-phase growth response to salinity for genotypes that differ in the rate at which salt reaches toxic levels in leaves (Munns, 2005) [87]

Mitigation of Salinity Stress through Salicylic acid (SA)

Salicylic acid is an endogenous plant growth regulator of phenolic nature that possesses an aromatic ring with a hydroxyl group or its functional derivative. Salicylic acid participates in the regulation of physiological process in plants and its synthesis can be induced by hydrogen peroxide derived from the reactive oxygen species during abiotic stress (Yalpini *et al*., 1994) [135].



Structure of Salicylic acid

It is believed that SA (ortho-hydrobenzoic acid) is a natural derivative of cinnamic acid, an intermediate in shikmic acid pathway, operative for the synthesis of phenolic compounds.

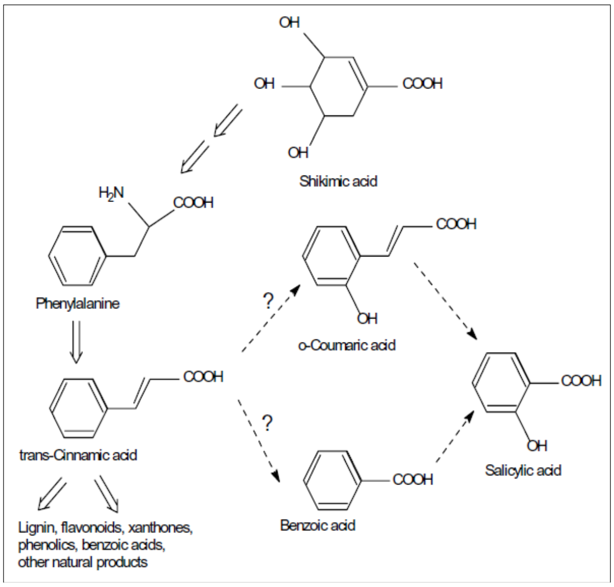


Fig 2: Proposed pathway for salicylic acid biosynthesis in plant Source: (Hayat *et al*., 2007) [49]

Salicylic acid (SA) is an endogenous growth regulator of phenolic nature, which participates in the regulation of physiological processes in plants such as growth, photosynthesis, nitrate metabolism, ethylene production, heat production and flowering (Hayat *et al*., 2010) [48] and also provides protection against biotic and abiotic stresses such as salinity (Kaya *et al*., 2002) [63]. Several mode of applications (soaking the seeds prior to sowing, adding to the hydroponic solution, irrigating, or spraying with SA solution) have been shown to protect various plant species against abiotic stress factors by inducing a wide range of processes involved in stress tolerance mechanisms (Horvath *et al*., 2007) [50]. The role of SA in defense mechanism to alleviate salt stress in plants was studied (Hussein *et al*., 2007) [52]. The ameliorative effects of SA have been well documented including salt tolerance in many crops such as bean (Azooz, 2009) [17], tomato (Tari *et al*., 2002) [125] and maize (Gunes *et al*., 2007) [44]. Exogenous application of salicylic acid enhanced the photosynthetic rate and also maintained the stability of membranes, thereby improved the growth of salinity stressed barley plants (El-Tayeb, 2005) [32]. SA added to the soil also had an ameliorative effect on the survival of maize plants during salt stress through decreasing the Na^+ and Cl^- accumulation (Gunes *et al*., 2007) [44]. SA treatment was accompanied by a transient increase in the H_2O_2 level. Root drenching with SA @ 0.1 mM protected tomato (*Lycopersicon esculentum*) plants against 200 mM NaCl stress (Stevens *et al*., 2006) [122]. It was found that the SA treatment caused accumulation of both ABA and IAA in wheat seedlings under salinity. However, the SA treatment did not influence on cytokinin content. Thus, protective SA action includes the development of anti stress programmes and acceleration of normalization of growth processes after removal of stress factors (Sakhabutdinova *et al*., 2003) [111]. The results obtained in the last few years strongly argue that SA could be a very promising growth regulator for the reduction of salinity stress in sensitive crops, because under certain conditions it has been found to mitigate the damaging effects of various stress factors in plants.

The effect of salicylic acid (SA) on morpho-physiological, biochemical parameters like photosynthetic pigments, protein content, proline, total soluble sugar and changes in antioxidant enzymes activity in different crops is reviewed as under:

Morpho-physiological traits

Soil salinity is a major intimidation in agriculture sector that affects the major morpho-physiological processes in plants at different growth stages. High salinity influences plants in several ways: water stress, ion toxicity, nutritional disorders, oxidative stress, alteration of metabolic processes, membrane disorganization, reduction of cell division and expansion, genotoxicity (Hasegawa *et al*., 2000; Munns, 2002; Zhu, 2007) [46, 86, 140]. The high sodium levels disturb potassium (K) nutrition and when accumulated in cytoplasm that inhibits many enzymes (Sharma, 1996) [120]. High concentrations of salts in the root zone decrease soil water potential and the availability of water (Lloyd *et al*., 1989) [78]. Murphy *et al*. (2003) [89] reported that salt stress affects plant physiology at both whole plant and cellular levels through osmotic and ionic stress. The salt tolerance potential varies from genotype to genotype and species to species within the plant kingdom (Moisender *et al*., 2002; El-Sheekh and Omer, 2002) [85, 34].

Seed germination is one of the most primary and vital phases in the growth cycle of plants that determine plant establishment and the yield of crops. The initial germination process is delayed under salt stress (Almansouri *et al*., 2001; Khajeh-Hosseini *et al*., 2003) [10, 65]. The inhibitory effect of NaCl stress on seed germination is due to an osmotic effect or ion toxicity (Rehman *et al*., 1996; Katembe *et al*., 1998; Pujol *et al*., 2000; Tobe *et al*., 2004) [103, 62, 101, 129], and salinity-induced declines in germination are usually due to an osmotic effect only for halophytes. It was also reported that Nonhalophytes are more likely to exhibit additional ion toxicity (Bajji *et al*., 2002) [19]. The reduction in germination percentages due to increasing soil salinity may be attributed to membrane damage and stimulate formation of ROS such as superoxide, hydrogen, hydroxyl radical (Wong *et al*., 2009) [134].

In sugar beet, higher concentration of NaCl caused reduction in growth parameters such as leaf area, root and shoot length, germination, fresh weight and dry weight and more of solute leakage (Ghoulam *et al*., 2002) [41]. Further, salinity stress affected plant growth and productivity during all developmental stages in cowpea (Hussein *et al*., 2007) [52], in sunflower (Kaya and Day, 2008) [64], in *Hordeum vulgare* and *Hordeum bulbosum* (Tavili and Biniaz, 2009) [128]. Salinity stress causes reduction in internodal distance and number of leaves plant^{-1} in various plant species and this reduction may be attributed due to the reduction in turgor potential, necessary for cell elongation (Iqbal and Ashraf, 2005) [55].

Salinity stress causes osmotic stress that adversely affected the yield and yield component. More findings indicate that in soybean there was a decrease in yield and yield attributing components (Dominique *et al*., 2007; Vicki Hufstetler *et al*., 2007; Masoumi *et al*., 2010) [29, 131, 80].

Several reports have been published in the last decade demonstrating the role of salicylic acid (SA) in seed germination. The SA-induced increase in the germination rate observed in the presence of NaCl may also be due to the activation of the second stage of germination, which corresponds to the embryo growth stage, through enhanced synthesis of proteins that are essential for germination (Rajjou *et al*., 2006) [102] and the activation of the mobilization of reserve metabolites with low molecular weights (Nonogaki *et al*., 2010) [94]. LEAs and HSPs are synthesized in the presence of exogenous SA and have been shown to enable germinating *Arabidopsis* seeds to show a marked tolerance to salt stress (Rajjou *et al*., 2006) [102]. Subsequently, Jadhav *et al.* (2011) [56] reported in groundnut that seed imbibitions with SA leads to activation of germination and seedling growth.

Salicylic acid has been reported to play role in mitigating the harmful effects on morpho-physiological parameters of salinity stress. Induction of multiple stress tolerance in plants by exogenous application of salicylic acid and its derivatives may have a significant practical application in agriculture, horticulture and forestry (Senaratna *et al*., 2000) [115]. Salicylic acid treatment alleviated the deleterious effect of salinity, drought and boron toxicity on plant growth. Those effects of salicylic acid on the growth of plants under salinity and drought support the findings of (Senaratna *et al*., 2000; Senaratna *et al*., 2003; Khan *et al*., 2003; Singh and Usha, 2003, Shakirova *et al*., 2003, and Sakhabutdinova *et al*., 2003) [115, 114, 67, 121, 119, 111].

Membrane stability index (MSI)

Salinity impaired the membrane stability by increasing electrolyte leakage which may be partly maintained by the application of Salicylic acid. Functions of biological membranes are very sensitive to environmental stress and stress-induced damage to membranes has been well documented in the plants (Nishida & Murata, 1996) [93]. It has been noted that maintaining integrity of cellular membranes under stress conditions is considered an integral part of salinity tolerance mechanisms. Lutts *et al.,* (1996) [76] who reported that salinity increased the membrane permeability of sensitive rice varieties. The membrane stability index (MSI) could be considered as a reliable physiological parameter to screen germplasm lines for salinity tolerance (Turner and Nicolas 1987) [130]. The higher leakage of solutes was probably due to enhanced H_2O_2 accumulation and lipid peroxidation under salt stress (Dionisio-Sese and Tobita 1998) [26]. The presence of NaCl in the rooting medium caused a disturbance in membrane permeability expressed by an increase in solute leakage in sugar beet and the leakage was higher in susceptible cultivars of sugar beet than tolerant ones, indicating severe membrane damage for the former under salt stress (Ghoulam *et al.*, 2002) [41]. The plants fed with NaCl exhibited a significant increase in electrolyte leakage compared to the control. Similar results were reported by Karlidag *et al*., (2009) [161] and Khan *et al*., (2010) [66]. Membrane stability index (MSI) decreased under salt stress in pea at high salinity and membranes damage increased with increase in salinity level, So MSI can be considered as very significant tool for evaluating the salt tolerance potential in pea (Shahid *et al*., 2012) [118].

Salicylic acid (SA) reduced electrolyte leakage in corn leaf, rice leaf and cucumber hypocotyls under chilling stress (Kang and Saltveit 2001) [59]. Similarly, SA reduced the amount of ion leakage (measured as electrolytes) in salt stressed tomato plants indicating that SA treatment has facilitated the maintenance of membrane functions (i.e., semi permeability) under stress conditions (Stevens *et al*., 2006) [122]. Whereas, foliar spray of salicylic acid (10^{-5} M) reversed the adverse effect of NaCl and caused a significant decrease in electrolyte leakage in the salt-treated plants (Idrees *et al*., 2011) [53]. Salicylic acid application reduced the adverse effect of salinity on membrane stability index (Fahad *et al*., 2012) [36].

Photosynthetic Pigments

Salinity stress causes decrease in plant growth and productivity by disrupting physiological processes, primarily photosynthesis. The accumulation of intracellular sodium ions at salt stress changes the ratio of K: Na, which affect the bio energetic processes of photosynthesis (Sudhir and Murthy, 2004) [123]. Effect of salinity stress on photosynthetic rate, 13C partitioning sugar and Na+ concentrations was measured. Effect of salinity stress on stems, a major sink, appeared within a few hours of treatment, whereas, the effects on photosynthetic rate were observed after a lag period of 3-4 days of salt application. Salinity stress reduced ^{13}C export rate. These results suggest that salinity impairs sink activity earlier than source activity (Ryuichi *et al*., 2006) [106]. A number of findings suggested that reduction in chlorophyll content under salinity stress causes reduction in photosynthesis and consequently low yields. Discernible reduction in chlorophyll content at 100 and 150 mM NaCl in stem and leaf of green gram (Muthukumarswamy and Panneerselvam, 1997) [90] in cucumber (Kaya and Higgs, 2002; Dina and Amal, 2002) [63, 25] and in cotton (Meloni, 2003) [81] have been reported over the control. Fernanda *et al*. (2004) [38] found that salt stress negatively affected leaf stomatal conductance and transpiration rate. At ultra structural level, only thylakoid swelling and a decrease in the amount of grana stacking were observed in treated plants. The higher concentration of NaCl causes significant reduction in total chlorophyll in pea (Ahmad and Jhon, 2005) [2]. Ashraf and Rasul (2005) [15]. Zayed and Zeid (2006) [138] observed significant reduction in chlorophylls a, and b, and total chlorophyll in two cultivars of mung bean (AuMg 588 and Mg 6601) while assessing their salt tolerance. After one week of salt application in pea, photosynthesis rate, stomatal conductance, transpiration rate, and chlorophyll contents were remarkably decreased with increasing salinity (Shahid *et al*., 2011) [117].

Salicylic acid (SA) ameliorated the adverse effect of salinity stress on photosynthetic pigments. Zhou *et al*. (1999) [139] reported that photosynthetic pigments were increased in corn with SA application. Salicylic acid appears to stimulate maize salt tolerance by activating the photosynthetic process (Khodary, 2004) [168]. Chlorophyll content increase with SA treatment confirmed the reports of El-Tayeb (2005) [32] in barley, Gunes *et al*. (2007) [44] in maize and Yildirim *et al*. (2008) [136] in cucumber.

Salinity showed destructive effect on chlorophyll a and b content in stressed plants (Saeidnejad *et al*., 2012) [108]. Although SA treatment reorganized seedlings chlorophyll structure and the chlorophyll content was increased along with increasing SA concentrations.

4. Protein content

Soluble protein content is an important indicator of physiological status of plants and the alternation of protein synthesis or degradation is one of the fundamental metabolic processes that may influence water stress tolerance (Ouvrard *et al*., 1996; Jiang and Huang, 2002) [97, 58]. Both quantitative and qualitative changes of proteins have been detected during the stress (Riccardi *et al*., 1998; Ahire *et al*., 2005; Kottapalli *et al*., 2009) [104, 1, 72]. Diverse findings indicate that reduction in protein content has been observed under salinity stress and this has been attributed to reduced synthesis and accelerated proteolysis. It may be due to decreased incorporation of amino acids into the proteins and denaturation of amino acids and protein synthesis under saline conditions (Levitt, 1972; Bernstein, 1974) [74, 20]. Total soluble protein content decreased in plants under NaCl stress reported in *Oryza sativa*, *Vicia faba*, *Amaranthus tricolor* and *Brugiera parviflora* (Alamgir *et al*., 1999; Gadallah, 1999; Parida and Das, 2005; Parvaiz and Satyavati, 2008; Wang and Nil, 2000) [9, 40, 98, 99, 132]. Doganlar *et al*. (2010) [128] studied the effect of salt stress on pigment and total soluble protein content in different varieties of tomato (*Lycopersicon esculentum* Mill.) who found that after 48 h of salt application total soluble protein content of all tomato cultivars were significantly decreased. Zahoor *et al*. (2011) [137] reported that maize seedlings were subjected to 0 and 150 mM NaCl for four week, salt stress caused a significantly decreasing effect on total soluble protein in leaves of all maize varieties. It has already been reported that salt and osmotic stresses can increase the expression of stress proteins. For example, Dani *et al*. (2005) [23] reported up-regulation of a 26 kDa germin-like protein in *Nicotiana tabacum* under salt stress. Plants produce proteins in response to abiotic and biotic stress and many of these proteins are induced by Phytohormones including salicylic acid (Naz, 2008) [91]. Study on maize conducted under saline conditions indicated that application of salicylic acid (SA) increases protein and amino acids (El-Tayeb, 2005) [32]. Azooz *et al*. (2009) [17] reported that in faba beans genotypes salicylic acid treatment increased the total protein in both root and shoot. Sahar (2011) [109] said that salicylic acid increases protein concentration and the highest level of protein content observed at 4 mm SA level with 12 dS/m salinity level in *Salvia officianlis*. Fahad *et al*. (2012) [36] revealed that the soluble protein content of maize leaves was increased under salinity stress as compared to untreated control.

5. Proline content

Proline plays an important role in mediating osmotic adjustment and protecting the sub-cellular structures in stressed plants. Arora and Saradhi (1995) [13] reported that the seedlings exposed to stress accumulated higher levels of proline in their shoots compared with control seedlings. Petrusa and Winicov (1997) [100] found that salt tolerant alfalfa plants rapidly doubled their proline content in the roots whereas, the activity of proline biosynthesis enzymes, pyrroline-5- carboxylate reductase and orthinine amino transferase increased considerably in jute in tolerant lines under salt stress. In contrast, the activity of proline degrading enzyme, proline oxidase, decreased under salt stress in the leaf tissues of all the lines of jute. Proline and quaternary ammonium compounds are key osmolytes that help plants to maintain cell turgor (Hsu *et al*., 2003, Seki *et al*., 2007) [51, 113]. A large number of plant species accumulates proline in response to salinity stress and their accumulation may play a role in defense against salinity stress. However, data do not always indicate a positive correlation between osmolytes accumulation and an ability to adapt to stress (Asharf and Harris 2004, Mansour 2000, Mansour *et al*., 2005) [14, 79, 78]. Proline may act as a signaling component of the adaptation process (Maggio *et al*., 2002) [77]. Several workers suggested that proline accumulation rapidly increased in plants in response to salinity stress as found in case of *Pisum sativum* (Ahmad and Jhon, 2005; Ahmad *et al*., 2008) [2, 6], *Phaseolus aureus* (Mishra and Gupta, 2005) [82], *Morus alba* (Ahmad *et al*., 2007) [8], *Sesamum indicum* (Koca *et al*., 2007) [70]. Farkhondeh *et al.* (2012) studied that effect of six different levels of salinity [@ 0.6, 4.2, 6.8, 9.7, 14.2 and 19 (ds m^{-1})] on two varieties of sugar beet (sbsi004 polymeric and Dorotea) and concluded that free proline in both varieties increased under salinity. Shahid *et al.* (2011) [117] investigated the performance of two salt tolerant and two salt sensitive pea genotypes (Ambassidar and PF-400). Salt stress significantly reduced the leaf proline in all pea genotypes as compared to control. The salt tolerant genotypes contained maximum leaf proline than sensitive genotypes. Similar findings were reported by Hassine and Lutts (2010) [47] in *Atriplex halimus* and Shahbaz *et al*., (2011) [116] in sunflower.

Proline is one of the most important osmoprotectants of plants defensive mixed action to salt stress. Increasing proline leads to increase in resistance to salt stress, but the amount of this increase is different between different varieties (Sairam *et al.*, 1998) [110]. Proline can be considered as a ROS scavenger, and plays a protective role in cellular structures, which can break down and provide carbon, nitrogen and energy sources after abiotic stress exposure to plants. Source of proline is total protein and total amino acid. Several findings were reported the increase of proline in plants exposed to salinity stress (Ehsanpour and Fatahian, 2003; Parida and Das, 2005; Hussein *et al*., 2007; Koca *et al*., 2007; Eraslan *et al*., 2007; Sakhanokho and Kelley, 2009) [31, 52, 70, 98, 35, 112].

According to the other studies, the proline accumulation by salicylic acid treatment increases in wheat, oat, bean and tomato, under oxidative stresses, (Tasgin *et al.*, 2006) [126]. The more tolerant plants store more proline (Desnigh and

Kanagaraj, 2007) [24]. Amin *et al*., (2009) [11] reported that increasing the amount of proline and sugars in plants would lead to the resistance against loosing water, protect turgor, reduce the membrane damage and accelerate the growth of plants under stress conditions. The higher accumulation of proline under stress conditions was attributed to enhanced activities of proline biosynthesis enzymes, ornithine aminotransferase and pyrroline-5-carboxylate reductase, as well as due to inhibition of proline degradation enzymes, proline oxidase and proline dehydrogenase (Kishor *et al*., 2005) [69].

Total soluble sugar

Soluble sugars participated in the osmotic adjustment of plants exposed to the salt stress. It is assumed that during germination and early seedling growth, cell division and enlargement require transportation of respiratory substrates in the form of soluble sugars and low molecular weight protein from seed storage organs to the site of growth (Bewley and Black, 1994) [21]. Salinity stress limited hydrolysis of food reserves from storage tissues as well as it impaired their translocation from storage tissue to developing embryo axes (Dubey, 1985; Lacerda *et al.*, 2003) [30, 73]. Tolerant varieties accumulated sucrose at a significantly greater level than did sensitive ones under non-ionic stress condition (Ildiko and Gabor, 2000) [54]. Fernando *et al.* (2000) [39] investigated the influence of NaCl on soluble sugar content in quinoa (*Chenopodium quinoa* Willd.) seeds and seedling components (cotyledons and embryonic axes) during early germination. Total soluble sugar content increased markedly in distilled water, peaking after 6 h for both embryonic axis and cotyledons. Reduced glucose and fructose contents were found in embryonic axes in the presence of NaCl. Dkhil and Denden (2010) [27] conducted an experiment in which okra (*A. esculentus* L., cv. Marsaouia) seeds were placed into NaCl solutions (@ 20, 40, 60, 80 and 100 mM NaCl). Results revealed that imposition of NaCl treatment causes significant increase in total sugar content in cotyledons and mainly in embryonic axes. The rate of increase under NaCl treatment was more pronounced in embryonic axes, Significant differences were observed between the various NaCl concentrations for total sugars in embryonic axes, whereas, the level of total soluble sugars increased to a smaller extent over stressed seeds.

Certainly, SA causes balance in the sugar level at salinity stress condition due to possibility of increase in induced glucose storage by salt stress. That is for storage demand reduction of carbon or starch decomposition (Tattini, 1996) [127]. Increase of all soluble carbohydrate in the root during salinity stress is effective on the balance against osmotic pressure. The plant cell for escaping from plasmolysis performance and creation during salt stress conditions should be changed and analysed from macro molecule to micro molecule. Sucrose breaks down to glucose and fructose and starch decomposition to glucose increases its osmotic pressure cell (El Midaoui *et al.*, 1999) [33]. The use of salicylic acid could activate the consumption of soluble sugar metabolism by increasing osmotic pressure. It is supposed that salicylic acid treatment deranges the enzymatic system of polysaccharide hydrolysis (Khodary, 2004) [68]. Salicylic acid applied plants leaves accumulated more compatible Osmolite's, e.g., soluble sugars, glucose and fructose, a sugar alcohol, sorbitol and proline (Szepesi, 2006) [124]. In Shara (*Plectranthus tenuiflorus*) plant SA enhanced the soluble sugar accumulation in both water-stressed and non-stressed plants (Jalal *et al.*, 2012) [57].

Antioxidant Enzymes Activity

Environmental stresses induce production of reactive oxygen species (ROS), viz., superoxide radicals, hydrogen peroxide (H_2O_2) and hydroxyl radicals (OH^-). These ROS cause oxidative damage to different cellular components including membrane lipids, protein and nucleic acids (Halliwell and Gutteridge, 1986) [45]. Reduction of oxidative damage could provide enhanced plant resistance to salt stress. Plants use antioxidants such as reduced glutathione (GSH) and different enzymes such as superoxide dismutases (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione-S-transferases (GST) and glutathione peroxidases (GPX) to scavenge ROS. Plants have the antioxidant enzymes for overcoming the harmful effects of salinity stress such as SOD, CAT, APX etc. Gomez *et al*. (2004) [42] found increase in all SOD isoenzymes of pea chloroplasts following a long term NaCl treatment. Koca *et al*. (2007) [71] reported that salinity causes to a decrease in SOD activity in salt sensitive plants of *Sesamum indicum* than salt tolerant ones. Under salt and water deficit stresses. Rubio *et al*. (2002) [105] reported that MnSOD and FeSOD were activated in the alfalfa transgenic chloroplast and nodular MnSOD isoforms were over-expressed as was FeSOD of chloroplasts. The first line of defense in oxidative stress is the action of SOD that converts $O_2^{-\bullet}$ to H_2O_2 (Mittler, 2002; Ashraf, 2009) [83, 16]. The increase in H_2O_2 is very harmful for the cells, hence it gets dismutated to water and oxygen with the help of another antioxidant enzyme catalase (Ashraf, 2009) [16]. One of the adaptive traits under salinity stress is increase in catalase activity which reduces the toxic levels of H_2O_2 and protects the cell from oxidative damage (Noreen *et al*., 2010) [96]. Another versatile antioxidant enzyme is ascorbate peroxidase which utilizes ascorbate as electron donor and scavenges H_2O_2 in water-water and ascorbate glutathione cycles. Hydrogen peroxide is reduced to water by APX and plays a role in cell defense mechanism (Kangasjarvi *et al*., 2008; Ashraf, 2009) [60, 16]. Type of differential response of cultivars differing in salt tolerance has already been observed in a number of crops, in which salt tolerant cultivars exhibited higher antioxidant enzyme activities than the salt sensitive cultivars (Ashraf, 2009; Noreen *et al*., 2009; Sabir *et al*., 2011) [16, 95, 107].

Plants have developed a complex antioxidative defense system, which enable plants to perform better under saline environments. Salicylic acid act as a potential non-enzymatic antioxidant as well as a plant growth regulator, which plays an important role in regulating a number of plant physiological processes including photosynthesis (Fariduddin *et al*., 2003; Singh and Usha, 2003; Waseem *et al*., 2006; Arfan *et al*., 2007) [37, 121, 133, 12]. Several literature reported the ameliorative role of exogenous applied SA on redox homeostasis and membrane functioning.

Various literatures suggested that effectiveness of SA in inducing stress tolerance depends upon type of species and its concentration applied (Borsani *et al*., 2001; Németh *et al*., 2002; Waseem *et al*., 2006; Arfan *et al*., 2007) [22, 133, 12]. Improvement or modification of plant growth and development can occur by the direct application of SA to seeds (Arfan *et al*., 2007; Azooz and Youssef, 2010) [12, 18]. El-Tayeb (2005) [32] has suggested that SA-induced increase in activities of antioxidant enzymes is responsible for salt stress tolerance in barley.

Conclusion

The aforementioned review of diverse studies made with different plant species signify the protective role of salicylic acid for extending abiotic stress research with special reference to salinity stress in different crops. The salinity stress has been observed to be widespread with every increasing day and thus, needs vital efforts and their dynamics for its gradual eradication in soil and in plants of economic significance so as to contribute for holistic development in the science of agriculture. Keeping these facts in view, it may be concluded that salicylic acid act as a potential growth regulator for better survival of the plants especially under salinity stress.

However, it may be summarised that Salinity stress may be mitigated by using control measures through strengthening susceptible / tolerant plant species by treating seeds or seedlings by innovative techniques like pre-soaking/hardening or foliar application with salicylic acid.

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