Induced Salinity Tolerance and Altered Ion Storage Factor in *Hordeum Vulgare* Plants Upon Salicylic-Acid Priming

H. PirastehAnosheh[1], Y. Emam[2]∗

[1]National Salinity Research Center, Agricultural Research, Education and Extension Organization (AREEO), Yazd, I.R. Iran
[2]Department of Crop Production and Plant Breeding, College of Agriculture, Shiraz University, Shiraz, I. R. Iran

∗ Corresponding Author: yaemam@shirazu.ac.ir

Shiraz University

ABSTRACT-This study was undertaken to better understand the probable mechanisms of salt stress tolerance induced by seed priming of salicylic acid (SA) in barley. Barley seeds were pre-soaked by SA or water and then sown under different saline watering regimes including 0.62 (tapwater), 5, 10 and 15 dS m^{-1}in petri dishes and then, the trend of water absorbing, seedling growth, germination rate and percentage were measured. After 11 days, seedlings were transplanted to pots and K$^+$ and Na$^+$ accumulation and storage factor were determined. The results showed that salt stress reduced absorbed water (50%), germination rate (39%), seedling growth (74%) and K$^+$ accumulation (38%) and increased Na$^+$ accumulation (fivefold). In all hours after sowing, SA-primed seeds had greater absorbed water with higher growth rate,which was true for all days after sowing. SA-primed seedlings had higher germination rate (30%) as well as shoot (17%) and root length (38%). Enhanced K$^+$ and reduced Na$^+$ accumulation were also found in SA-primed seedlings. Reduction in Na$^+$absorption due to SA application was found to be greater at lower salinity stress levels, which was consistent with its effect on seedling growth. Storage factor, devised for quantifying partitioning of absorbed ions, was found to be increased for K$^+$ and decreased for Na$^+$ at higher salt stress levels, which means that at higher salinity levels, greater Na$^+$ and lower K$^+$ were transported to the shoot and this was associated with greater loss in seedling growth. Indeed, SA-primed seedlings showed a greater Na$^+$ storage factor; i.e., they kept more Na$^+$ in their roots, in non- and light salt stress treatments. Accelerated water imbibition, greater germination rate, less Na$^+$, higher K$^+$ accumulation, and greater Na$^+$ storage in roots might be some mechanisms for salt stress tolerance in SA-primed barley seedlings.

INTRODUCTION

Salinity is one of the major abiotic stresses limiting the productivity of farming systems worldwide. While improvements in land and water management might solve the problem, improving the tolerance of crop species to salinity will also contribute to the increase in productivity. The reductions in crop growth from salinity stress are the consequences of osmotic stress inducing a water deficit and excess Na$^+$ and Cl$^-$ ions with negative impacts on biochemical processes (Syeed et al., 2011; Jafar et al., 2012; Khan et al., 2014). Plant growth and development can be affected by salinity stress at any time during the crop life cycle. Barley experiences salinity stress at different developmental stages, such as germination, vegetative and reproductive growth phases.

Salicylic acid (SA) is known as a signalling molecule that modifies plant responses to pathogen infection. In addition to being an important component of biotic stress tolerance mechanism, SA also regulates various aspects of plant responses to abiotic stresses through signalling cross-talk with other growth hormones (Ashraf et al., 2010; Hayat et al., 2010). In particular, SA plays a key role in plant adaptive responses to osmotic stress, high salinity, oxidative stress, high temperature and frost stresses (Pirasteh-Anosheh et al., 2012). The exogenous application of SA can reduce toxicity symptoms induced by salinity stress in many crop species (El-Tayeb, 2005; Nazar et al., 2011; Syeed et al., 2011; Khan et al., 2014). For example, it has been shown that SA application reduced concentration of indole-3-acetic acid and cytokinin in salt-stressed wheat plants, which consequently resulted in better cell division in root apical meristem and increased growth and productivity (Shakirova et al., 2003). The ability of exogenously applied SA to improve photosynthetic capacity, increase accumulation of soluble carbohydrates, increase ATP content and maintain optimum K/Na ratio under saline conditions

has been suggested as potential mechanisms of slat tolerance in plants (Ashraf et al., 2010; Hayat et al., 2010). However, the important role of SA in ion transport processes (e.g. Na^+, K^+) at germination stage has been overlooked during slat stress.

Seed priming with SA has been shown to be an effective approach in counteracting harmful effects of salt-stress in many crops such as barley (Ashraf et al., 2010). SA seed priming positively affected the osmotic potential, shoot and root dry mass, potassium to sodium ion concentration ratio and photosynthetic pigments under saline conditions (Kaydan et al., 2007). Shakirova et al. (2003) indicated that SA seed priming resulted in the accumulation of ABA that might have contributed to pre-adaptation of seedlings to salinity. To determine the optimum conditions for each priming technique, factors such as concentration and volume of priming agent, seed soaking time, when and how the seeds are dried after priming, and subsequent seed storability must be investigated (Ashraf et al., 2008; Pirasteh-Anosheh et al., 2014a).

Recently, many researchers have focused on seed priming with plant growth regulators (PGRs), especially under stress conditions; however, details of such mechanisms are not yet been fully understood. Thus, in this study, answers to the following questions are sought: whether or not SA priming improves water absorption under salinity conditions. What is the impact of SA on early growth pattern? Whether or not SA alters ion accumulation in root and shoot.

MATERIALS AND METHODS

This study was conducted at Cereal Laboratory of College of Agriculture, Shiraz University during 2014. The treatments were arranged in a completely randomized design with 8 replicates, which included four levels of salinity: 0.67 (tapwater, as control), 5, 10 and 15 dS m^{-1} and three levels of seed priming: non-primed, hydro- and SA-primed. Hydro-priming treatments were imposed to distinguishthe water effect from SA effects.

Uniform seeds of barley (*Hordeumvulgare* L. cv. Reyhane) were surface-sterilised for 5 min in sodium hypochlorite solution and then in 96% ethanol for 30 seconds (Dolatabadian et al., 2008). Dry seeds, without any pre-soaking, were used in non-primed treatments. While in the hydro- and SA-priming treatments, seeds were soaked in distilled water and SA solution (1 mM), for 12 h., respectively. The ratio of seed weight to priming solution volume was 1:5 g ml^{-1} (Farooq et al., 2006). Primed seeds were surface washed with distilled water and dried to their original weight under shade for 30 min and instantly were sown in 9-cm sterile petri dishes on two layers of filter paper (Whatman No. 2). The petri dishes were kept in a germinator at 25°C. Salinity treatments were applied from the beginning of the experiment. Saline solutions (5, 10 and 15 dS.m^{-1}) were made by NaCl: CaCl$_2$ with 2:1 molar basis ratio (Maggio et al., 2007), and their EC were controlled by a

portable EC-meter. The papers were replaced every two days to prevent salt accumulation (Emam and Pirasteh-Anosheh et al., 2014).

Measured traits in petri dishes included the trend of absorbed water and seedling growth as well as germination percentage and rate and shoot and root length. Absorbed water was measured at 0.5, 1, 2, 3, 4, 5 and 6 hours after sowing (HAS). In each sampling, the amount of absorbed water was achieved by subtracting seeds dry weight from swollen seeds.Root and shoot growth pattern was determined daily until 7 DAS. In each sampling, 10 seedlings were randomly selected from each dish. Seed germination was recorded daily up to 7 days after the beginning of the experiment and germination percentage and germination rate were calculated. A seed was considered germinated when the radicle emerged about 2 mm in length. Both root and shoot lengths were considered as seedling growth.

At 11 days after sowing (DAS), 10 seedlings from each petri dish were transplanted into 5 L pots and at 18 DAS, seedlings were thinned to 5 per pot. To maintain consistency of salinity throughout the experiment, EC of pot drainage was also controlled by portable EC-meter. The salinity treatments were continued in pots. The averages of EC of drainage during the experiment were 6.45, 12.05 and 16.81 dS.m^{-1} for 5, 10 and 15 dS.m^{-1} salinity treatments, respectively. Measured traits in pot included sodium (Na^+) and potassium (K^+) concentration in shoot and root as well as storage factor index for them. Sodium and potassium concentrationin shoot and root tissues were measured using a flame photometer for 31-day-old seedlings. Storage factor (SF) was devised for Na^+ and K^+ to quantify ion partitioning between root and shoot and was calculated as:

$$SF = \frac{RI}{TAI}$$

where RI and TAI are root ion accumulation and total amount of that ion absorbed, respectively. Indeed, the storage factor (SF) refers to the proportion of any ion (e.g. Na^+ or $K^{+)}$ which remains in the root cells. A SF value of zero means that almost all absorbed ions are transported to the shoot whereas a value of 1 means that all absorbed ions are stored in the root. More Na^+ accumulation in roots and lower transportation to the shoot is considered as a mechanism for higher salinity tolerance in plants (Davenport et al., 2005); thus, higher SF could be used as an index of having higher potential for salinity tolerance. The collected data were subjected to the analysis of variance. Significant differences between the means were determined based on the least significant difference (LSD) test at P 0.01 or standard error (±SE) using SAS *v*.9.1 software.

RESULTS AND DISCUSSION

Water absorption showed a sharp increasing trend within the first hour after sowing (HAS) in all treatments (Fig. 1 A and B). Salinity decreased water

absorption, and this reduction was closely associated to salt stress level. SA seed priming increased water absorbed in all salinity treatments. From 3 to 6 HAS, water absorbed in 5dS m^{-1} salinity treatment (ST) was lower than that of tapwater (TW) in non-primed treatment (Fig. 1A) while in SA-primed seeds, water absorbed in 5ST treatment was significantly less than that of TW in all times after sowing (Fig. 1B). Water absorption stopped 1-2 HAS in non-primed treatment whereas SA primed seeds, especially under non- and light salt stress conditions, absorbed water until the end of the experiment (Fig. 1A and 1B).

Total absorbed water was significantly different among non-primed, hydro and SA primed seeds (Table 1). SA priming increased total absorbed water in tapwater (TW), 5 (5ST), 10 (10ST) and 15 (15ST) dS m^{-1} salinity treatments by 35.0, 47.6, 50.0, 54.5 and 50.0% compared to non-primed seeds, respectively. There was no significant difference between 10ST and 15STunder three priming conditions, in terms of absorbed water (Table 1). Germination percentage did not show any significant difference among the treatments so that all reached the maximum germination percentage (100%), even at the highest salinity level (Table 1).
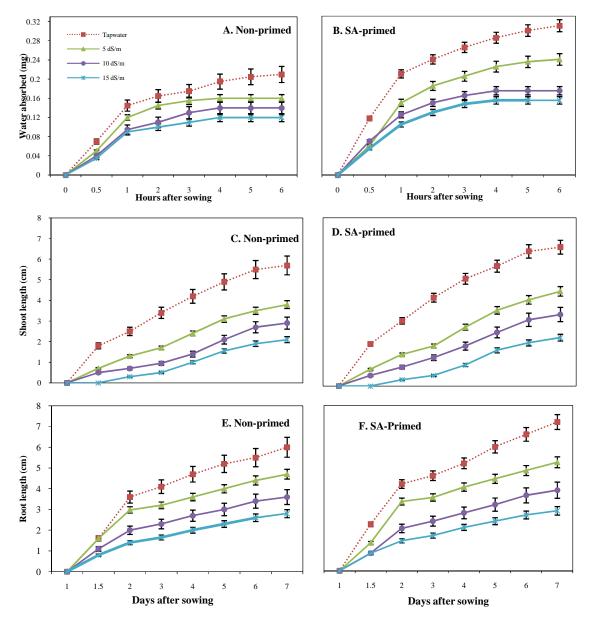

Fig. 1. Water absorption (A and B), shoot (C and D) and root (E and F) growth patterns for salicylic acid (SA) primed barley seedlings under different salinity treatments (0: 0 dS m^{-1}, TW: Tapwater). Vertical bars represent standard error(±SE).

Contrary to germination percentage, there were remarkable differences among the treatments in terms of germination rate. SA priming increased germination rate in TP, 5ST and 10 ST compared to non- and hydro primed treatments; however, at higher salinity levels (i.e. 10ST and 15ST), no significant difference was found between non- and hydro priming treatments (Table 1).

Salinity significantly decreased shoot length in all three priming conditions (Table 1). SA priming increased shoot length in 5 ST (15.5%) and 10 ST (14.7%); however, there was no significant difference between shoot length of non-primed (2.10 cm), hydro primed (2.23cm) and SA primed (2.29 cm) treatments in 15 ST (Table 1). Salinity at every level decreased shoot length throughout the experiment, and these reductions were closely associated with salt stress severity. SA-primed seedlings, in all salinity treatments, had greater shoot growth than those of non-primed seedlings. Although SA priming had a positive effect on shoot length, the differences between salinity levels were kept even under SA seed priming (Fig. 1 C and D). Although salt stress decreased radicle length in all three priming treatments, reductions in non-and hydro primed were greater compared to those of SA primed plants (Table 1). SA priming increased radicle length in all salinity levels compared to non-and hydro primed treatments. SA priming increased radicle length by 20.4, 46.2, 54.8 and 40.9% at TW, 5ST, 10ST and 15ST treatments,

respectively. These amounts were 18.6, 39.9, 48.6 and 40.0% for comparing with hydro priming. There was an increasing trend in radicle length with time in all treatments (Fig. 1 E&F). Radicle lengths of SA-primed seedlings were greater from the beginning of the experiment, which was kept until the last sampling. Although radicle length was negatively affected by salt stress, it was increased by SA priming, except in 15STwhere there was no significant difference between SA-primed and no-primed radicle length.

Salinity increased sodium ion (Na^+) accumulation in shoot and root tissues so that in both SA- and non-primed conditions, the highest and the lowest Na^+ were observed in both shoot and rootin 15ST and tap water, respectively. There was no significant difference between shoot and root Na^+ in SA- and non-primed treatments under 15ST; however, SA priming reduced shoot and root Na^+ at lower salt levels (Table 2). The results also showed that shoot and root potassium ion (K^+) accumulation decreased due to salt stress. The reduction in K^+ was associated with salinity level so that the lowest shoot and root K^+ was observed in 15 ST (Table 2). Salinity reduced Na^+ storage factor in both SA- and no-primed treatments. Alteration in storage factors was closely associated with salt stress level so that 15ST treatment had the lowest storage factors (Table 2). An inverse trend was observed for K^+ storage factor; in other words, K^+ storage factor increased along with the increase in salinity levels (Table 2).

Table 1. Comparison of hydropriming with salicylic acid (SA) priming effects on barley seed germination traits

Salinity level (dS m⁻¹)	Total absorbed water (mg) Non-primed	Primed Hydro	SA	Germination % Non-primed	Primed Hydro	SA	Germination rate (d⁻¹) Non-primed	Primed Hydro	SA	Shoot length (cm) Non-primed	Primed Hydro	SA	Radicle length (cm) Non-primed	Primed Hydro	SA
Tap water	0.21ᶜ	0.20ᶜ	0.31ᵃ	100.0ᵃ	100.0ᵃ	100.0ᵃ	29.00ᶜ	33.45ᵇ	36.86ᵃ	5.72ᵇ	6.31ᵃᵇ	6.66ᵃ	6.02ᵇ	6.11ᵇ	7.25ᵃ
5	0.16ᵈ	0.18ᶜᵈ	0.26ᵇ	100.0ᵃ	100.0ᵃ	100.0ᵃ	24.21ᵈ	26.21ᶜᵈ	32.35ᵇ	3.84ᵈ	4.12ᶜᵈ	4.58ᶜ	4.76ᵈ	4.98ᵈ	6.97ᵃᵇ
10	0.11ᵉ	0.14ᵈᵉ	0.17ᵈ	100.0ᵃ	100.0ᵃ	100.0ᵃ	21.42ᵈᵉ	24.62ᵈ	28.42ᶜ	2.93ᶠ	3.02ᶠ	3.47ᵉ	3.61ᶠ	3.76ᵉᶠ	5.59ᶜ
15	0.10ᵉ	0.11ᵉ	0.15ᵈ	100.0ᵃ	100.0ᵃ	100.0ᵃ	19.92ᵉ	20.45ᵉ	21.06ᵉ	2.10ᵍ	2.23ᵍ	2.29ᵍ	2.88ᵍ	2.90ᵍ	4.06ᵉ
Mean	0.14B	0.15B	0.22A	100.0A	100.0A	100.0A	22.88C	26.18B	29.67A	3.64B	3.92B	4.25A	4.31B	4.43B	5.96A

Means followed by the same letter within each variable do not differ significantly based on LSD at P< 0.01

Table 2. The effect of priming with salicylic acid (SA) on Na^+ and K^+ ions accumulation in barley seedlings

Salinity level (dS m⁻¹)	Shoot Na^+ Non-primed	SA-Primed	Root Na^+ Non-primed	SA-Primed	Na^+ Storage factor Non-primed	SA-Primed
Tap water	1.91ᵈ	0.77ᶠ	4.23ᵉ	2.89ᶠ	0.69ᶜ	0.79ᵃ
5	3.81ᶜ	1.95ᵈ	8.90ᶜ	5.81ᵈ	0.70ᶜ	0.75ᵇ
10	7.13ᵇ	4.59ᶜ	11.40ᵇ	8.61ᶜ	0.62ᵈᵉ	0.65ᵈ
15	9.84ᵃ	8.94ᵃ	15.55ᵃ	14.65ᵃ	0.61ᵉ	0.62ᵈᵉ

Salinity level (dS m⁻¹)	Shoot K^+ Non-primed	SA-Primed	Root K^+ Non-primed	SA-Primed	K^+ Storage factor Non-primed	SA-Primed
Tap water	17.61ᵃ	17.72ᵃ	16.82ᵃ	16.70ᵃ	0.49ᵇ	0.49ᵇ
5	17.92ᵃ	17.75ᵃ	16.76ᵃ	16.54ᵃ	0.48ᵇ	0.48ᵇ
10	11.43ᵇ	16.54ᵃ	13.87ᵇᶜ	15.43ᵃᵇ	0.54ᵃ	0.48ᵇ
15	8.65ᶜ	10.38ᵇ	10.73ᵈ	12.43ᶜ	0.55ᵃ	0.54ᵃ

Means followed by the same letter within each variable do not differ significantly based on LSD at P< 0.01

The highest water absorption occurred up to one hour after sowing, and after that, its gradient decreased. The seeds grown under tapwater treatments had higher absorbed water, which reduced due to salinity, depending on salinity level (Fig. 1 A&B). Salt stress reduces water absorption due to lowered osmotic potential of the medium and causes changes in metabolic activity. When dissolved salt concentrations in soil solutions increase, water energy gradients decrease, making it more difficult for water and nutrients to move through root membranes and into the plant; so, the rate of water and solute uptake slows, however, does not cease (Volkmar et al., 1998; Pirasteh-Anosheh et al., 2014a). SA priming increased water absorption in all salinity levels. This enhanced water absorption in SA-primed seeds led to higher germination rate and seedling growth so that SA-primed seeds had higher final germination rate, as well as, final shoot and root length. This argument was reflected in significant regression between absorbed water and seedling growth, which was greater under SA-priming conditions (Fig. 2).

There is no/little information about the possible effect of SA on water absorption by primed seeds. However, it is likely that increased absorbed water by the primed seeds could be due to the effect on softening of pericarp of imbibed seeds. It is argued that when the pericarp becomes soft due to SA-priming, it could allow more influx of water into the seed. Enhanced absorbed water as affected by SA priming might be a reason for enhanced germination and growth of barley in such conditions. Uhvits (1946) indicated that the seed hydration declined as the concentration of NaCl increased. Where germination percentage is very low, the average absorption is also uniformly low. Our results suggested that there is a significant relationship between absorbed water and seedling growth for both non- and SA-primed conditions (Fig. 2).

Since in all treatments full germination was achieved, salinity and SA- priming had no significant effect on seed germination percentage. Although seeds in saline conditions reached maximum germination percentage, their germination rate and subsequent growth, such as shoot and root length, reduced. Contrary to germination percentage, the rate of germination responded significantly to the treatments. SA-priming positively affected germination rate only in non- and low-salt stress levels. Germination rate of SA-primed seeds enhanced by 27.1, 33.6, 32.6 and 5.7% under TW, 5, 10 and 15 dS m^{-1}, respectively. Enhanced germination rate in SA-primed seeds could be attributed to improved water absorption (showed in the present study) and/or accelerated cell division (Ashraf et al., 2010) as well as other physiological changes (Dolatabadian et al., 2008). Our results confirm the finding of Jafar et al. (2012) and Dolatabadian et al. (2008) who showed that SA-priming enhanced wheat germination rate and produced vigorous seedlings under saline conditions.

Seedling growth also positively responded to SA-priming only in non-, light and mid-salt stress. As salinity increased, the effect of SA priming on shoot length decreased. The differences between SA primed and non-primed seedling shoot length were observed in TW, 5, 10 and 15ST at 1, 1.5, 2 and 4 DAS, respectively. So as salinity increased, the positive effect of SA-priming appeared later. The positive effect of SA-priming on radicle length was closely correlated with salinity level so that the highest effect was observed in 10ST while this effect was lower in 15ST. The positive effect of SA priming on shoot length was negligible in 15ST. Under saline conditions, SA-primed seedlings accumulated higher amounts of compatible osmolytes such as soluble sugars, glucose, fructose, sorbitol, and proline as well as enhanced photosynthetic pigments which resulted in better photosynthetic efficiency and growth (Ashraf et al., 2010; Khan et al., 2014). In the research done by Deef (2007), it was shown that SA-treated barley and wheat seedlings had elevated glutathione, a potential non-enzymatic antioxidant level. It was also reported that SA caused higher salt tolerance in primed seedlings. Accumulation of betaine was also high in the salt stressed seedlings of both species raised from primed seeds (Deef, 2007).
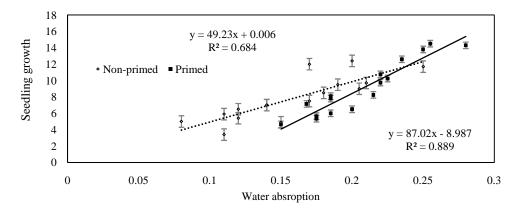

Fig. 2. Relationship between water absorption and seedling growth in barley seedlings in non- and SA-primed conditions. Vertical bars represent standard error (±SE).

Glycine betaine as an osmo-protectant stabilises quaternary structures of proteins against the adverse impact of salt stress. In photosynthesis, betaine efficiently protects various components of the photosynthetic machinery such as Rubisco and photosystem II from salt induced inactivation and dissociation into subunits (Khan et al., 2014). Enhanced seedling growth in SA-primed seeds also might contribute to greater water absorption in these seeds which is shown in Fig. 2. Accumulation of ions in shoot and root was influenced by salinity so that salt stress increased Na^+ and decreased K^+ in both shoot and root. The positive effect of SA-priming in modulating ion accumulation changes was observed in both shoot and root. Salt stress is known to alter the ion equilibrium in plant tissues and resultantly, some important ions could be effectively used as important selection criteria for salt tolerance (Pakniyat et al., 2003; Kausar et al., 2013). For example, salt stress may negatively affect photosynthesis by causing excess accumulation of leaf Na^+ and Cl^- (Nazar et al., 2011). In all salinity treatments, except 15ST, SA-primed seedlings had the lower shoot and root Na^+ accumulation. As it was discussed above, SA-priming compensated for the loss in barley seedling growth in non-, light and moderate stress and had no significant effect under the highest stress. This might be due to its effect on Na^+ accumulation; that is, in these conditions, SA-priming could not reduce Na^+ and consequently had no positive effects on seedling growth. It has been well known that the lower plant Na^+ accumulation can be associated with salt tolerance in barley seedlings (Gorham et al., 1994; Pakniyat et al., 2003; Pirasteh-Anosheh et al., 2014b), a cation having adverse effects on crops due to its toxic effects. El-Tayab et al. (2005) reported reduced Na^+ and enhanced K^+ in SA-treated plants in barley, Kaydan et al. (2007) in wheat and Nazar el al. (2011) in mungbean. Also, the primed seedling with higher K^+/Na^+ ratio had greater seedling emergence as well as shoot and root dry mass. Khan et al. (2014) showed that reduction of Na^+ and Cl^- content under salt stress is attributed to the increased glycine betaine content by SA application. The impact of SA on reducing Na^+ in the current study might result in lower oxidative damage induced by salt stress.Nazar et al. (2011), too, reported that salt-sensitive mungbean cultivar accumulated higher Na^+ and Cl^- in leaves and therefore, exhibited greater content of H_2O_2, lipid peroxidation and electrolyte leakage.

Although salinity reduced shoot and root K^+ accumulation in both non- and SA-primed seedlings, this reduction was observed in SA-primed seedlings at higher salinity level; in other words, SA priming prevented K^+ reduction at salinity level lower than 15ST. SA priming increased K^+ accumulation in 10 and 15ST which means that SA priming could increase K^+, only when salinity reduced its accumulation. K^+ accumulation is thought to be an index of salinity tolerance in most crop species (Ashraf et al., 2008). Pakniyat et al. (2003) and Pirasteh-Anosheh et al. (2014b) also noted that higher K^+ accumulation was associated with salt tolerance in barley. Increased K^+ in SA-primed seedlings found in our study was in agreement with the results of previous research (El-Tayab 2005; Kaydan et al., 2007; Pirasteh-Anosheh et al., 2014b). Syeed et al. (2011) suggested that SA application resulted in higher K^+ concentration and lower concentration of Na^+ in the cytosol by regulating the expression and activity of K^+ and Na^+ transporters and H^+ pumps which generate the driving force for translocation. Increased K^+ storage factor at the highest salt stress level showed that K^+ was less transported to the leaves at higher salinity levels.

SA primed seedlings showed greater Na^+ storage factor under TW and 5ST conditions. This could be a reason for SA to modulate salt stress adverse effects under these conditions. More Na^+ accumulation in roots and lower transportation into shoot appeared to be a mechanism to higher salinity tolerance of plants (Blumwald et al., 2000; Davenport et al., 2005). SA-primed seedlings had a greater storage factor which means that the higher proportion of absorbed Na^+ was stored in roots, and not transported into the leaves. A similar finding was reported by Davenport et al. (2005) who showed that the rate of Na^+ transfer from the root to the shoot (xylem loading) was much lower in the salt tolerant plants.

CONCLUSIONS

Accelerated water imbibition at first hours after SA-priming and greater growth in SA-primed seedlings at first days after SA-priming indicated that positive effect of SA-priming appeared from the beginning of the priming. Enhanced Na^+ and reduced K^+ accumulation was significantly compensated for by SA-priming and was consistent with SA effect on seedlings growth. Furthermore, the increase in salt stress levels was correlated with enhanced K^+ and reduced Na^+ storage factor. This means that at higher salinity levels, more Na^+ and less K^+ were transported to the shoot, which resulted in greater loss in growth. SA-priming could increase Na^+ storage factor at no stress and lower salt stress levels. Overall, accelerated water imbibition, greater germination rate, less Na^+, higher K^+ accumulation, and greater Na^+ storage in roots might be considered as possible mechanisms for salt stress tolerance in SA-primed barley seedlings.

REFERENCES

Ashraf, M., Akram, N.A., Arteca, R.N., & Foolad, M.R. (2010). The Physiological, biochemical and molecular roles of brassinosteroids and salicylic acid in plant processes and salt tolerance. *Critical Review in Plant Science*, 29, 162-190.

Ashraf, M., Athar, H.R., Harris, P.J.C., & Kwon, T.R. (2008). Some prospective strategies for improving crop salt tolerance. *Advanced Agronomy*, 97, 45-110.

Blumwald, E., Aharon, G.S., & Apse, M.P. (2000). Sodium transport in plant cells. *Biochimica et Biophysica Acta*, 1465, 140-151.

Davenport, R., James, R.A., ZakrissonPlogander, A.Z., Tester, M., & Munns, R. (2005). Control of sodium transport in durum wheat. *Plant Physiology,* 137, 807-818.

Dolatabadian, A., Mohammad, S.A., Sanavy, M., & Sharif, M. (2008). Effect of salicylic acid and salt on wheat seed germination. *ActaAgriculturae Scandinavica, Section B. Soil and Plant Science*, 1–9.

ElTayeb, M.A. (2005). Response of barley grain to the interactive effect of salinity and salicylic acid. *Plant Growth Regulation*, *42*, 215-224.

Farooq, M., Basra, S.M.A., & Hafeez, K, (2006). Seed invigoration by osmohardening in coarse and fine rice. *Seed Scienceand Technology,* 34, 181-187.

Gorham, R.G., Papa, R., & Aloy-Leonard, M. (1994). Varietal differences in Na uptake in barley cultivars exposed to soil salinity or salt spray. *Journalof Experimental Botany*, 45, 895-901.

Hayat, Q., Hayat, S., Irfan, M., & Ahmad, A. (2010). Effect of exogenous salicylic acid under changing environment: A review. *Environmental and Experimental Botany*, 68, 14-25.

Jafar, M.Z., Farooq, M., Cheema, M.A., Afzal, I., Basra, S.M.A., Wahid, M.A., Aziz, T., & Shahid, M. (2012). Improving the performance of wheat by seed priming under saline conditions. *Journal of Agronomy and Crop Science*, 198, 38-45.

Kausar, F., Shahbaz, M., & Ashraf, M. (2013). Protective role of foliar-applied nitric oxide in *Triticumaestivum*under saline stress. *Turkish Journal of Botany*, 37, 1155-1165.

Kaydan, D., Yagmur, M., & Okut, N. (2007). Effects of salicylic acid on the growth and some physiological characters in salt stressed wheat (*Triticumaestivum* L.). *TarimBilimleriDergisi*, 13, 114-119.

Khan, M.I.R., Asgher, M., & Khan, N.A. (2014). Alleviation of salt-induced photosynthesis and growth inhibition by salicylic acid involves glycine betaine and ethylene in mungbean (*Vignaradiata* L.). *Plant Physiologyand Biochemistry*, 80, 67-74.

Maggio, A., Raimondi, G., Martino, A., & De Pascale, S. (2007). Salt stress response in tomato beyond the salinity tolerance threshold. *Environmental and Experimental Botany, 59, 276–282.*

Nazar, N., Iqbal, N., Syeed, S.,& Khan, N.A. (2011). Salicylic acid alleviates decreases in photosynthesis under salt stress by enhancing nitrogen and sulfur assimilation and antioxidant metabolism differentially in two mungbean cultivars. *Journalof Plant Physiology*, 168, 807-815.

Pakniyat, H., Kazemipour, A., & Mohammadi, G.A. (2003). Variation in salt tolerance of cultivated (*Hordeumvulgare* L.) and wild (*H. spontanum* C. KOCH) barley genotypes from Iran. *Iran Agricultural Research*, 22, 45-62.

PirastehAnosheh, H., Emam, Y., Ashraf, M., & Foolad, M.R. (2012). Exogenous application of salicylic acid and chlormequat chloride alleviates negative effects of drought stress in wheat. *Advanced Studiesin Biology*, 11, 501-520.

PirastehAnosheh, H., Emam, Y., & Ashraf, M. (2014a). Impact of cycocel on seed germination and growth in some commercial crops under osmotic stress conditions. *Archives of Agronomy and Soil Science*, 60, 1277-1289.

PirastehAnosheh, H., Ranjbar, G., Emam, Y., & Ashraf, M. (2014b). Salicylic-acid–induced recovery ability in salt-stressed *Hordeum vulgare* plants. *Turkish Journal of Botany*, 37, 112-121.

Shakirova, F.M., Sakhabutdinova, A.R., Bozrutkova, M.V., Fatkhutdinova, R.A., & Fatkhutdinova, D.R. (2003). Changes in the hormonal status of wheat seedlings induced by salicylic acid and salinity. *Plant Science*, 164, 317-322.

Syeed, S., Anjum, N.A., Nazar, R., Iqbal, N., Iqbal, N., Massod, A., & Khan, N.A. (2011). Salicylic acid-mediated changes in photosynthesis, nutrients content and antioxidant metabolism in two mustard (*Brassica juncea* L.) cultivars differing in salt tolerance. *Acta physiologiae plantarum*, 33, 877-886

Uhvits, R. (1946). Effect of osmotic pressure on water absorption and germination of alfalfa seeds. *American Journal of Botany*, 33, 278-285.

Volkmar, K.M., Hu, Y., & Steppuhn, H. (1998). Physiological responses of plants to salinity: A review. *Canadian Journal of Plant Science*, 78, 19-27.

القای تحمل به شوری و تغییر فاکتور ذخیره‌سازی‌یون در جو (*Hordeum vulgare*) با پیش‌تیمارسالیسیلیک‌اسید

هادی پیرسته انوشه¹، یحیی امام²*

¹مرکز ملی تحقیقات شوری، سازمان تحقیقات، آموزش و ترویج کشاورزی یزد، یزد ، ج. ا. ایران
²گروه زراعت و اصلاح نباتات، دانشکده کشاورزی، دانشگاه شیراز، شیراز، ج. ا. ایران.

*نویسنده مسئول

چکیده- این مطالعه به منظور درک بهتر مکانیسم‌های احتمالی القای تحمل تنش شوری توسط پیش‌تیمارسالیسیلیک‌اسید در جو اجرا شد. بذور جو با سالیسیلیک‌اسید یا آب پیش‌تیمار شده و سپس تحت شرایط متفاوت شوری آب آبیاری شامل ۰/۶۲ (آب شهر)، ۵، ۱۰ و ۱۵ دسی‌زیمنس بر متر در پتری‌دیش کشت شدند، و روند جذب آب و رشد گیاهچه و درصد و سرعت جوانه‌زنی شد. گیاهچه‌ها ۱۱ روز پس از کشت به گلدان انتقال داده و غلظت سدیم و پتاسیم و فاکتور ذخیره‌سازی محاسبه شدند. نتایج نشان داد که تنش شوری باعث کاهش جذب آب (۵۰٪)، سرعت جوانه‌زنی (۳۹٪) و رشد گیاهچه (۷۴٪) و کاهش تجمع پتاسیم (۳۸٪) و افزایش تجمع سدیم (۵ برابر) گردید. در همه ساعات پس از پیش‌تیمارسالیسیلیک‌اسید، بذور پرایم شده جذب آب بیشتری داشتند، و همچنین رشد گیاهچه‌های تیمار شده در همه روزهای پس از کاشت بهتر بود. گیاهچه‌های‌پیش‌تیمار شده با سالیسیلیک‌اسید سرعت جوانه‌زنی (۳۰٪) و طول ریشه (۱۷٪) و ساقه (۳۸٪) بیشتری داشتند. همچنین، افزایش غلظت پتاسیم و کاهش غلظت سدیم در اثر کاربرد پیش‌تیمار مشاهده شد. کاهش در جذب سدیم در اثر کاربرد سالیسیلیک‌اسید در سطوح پایین شوری بیشتر بود که با تاثیر آن بر رشد گیاهچه‌ها همخوانی داشت. فاکتور ذخیره‌سازی، که برای کمی‌سازی تسهیم یون‌ها طراحی شد، در اثر تنش شوری به ترتیب برای یون‌های پتاسیم و سدیم افزایش و کاهش نشان داد، که بدان معنی است که در سطوح بالاتر شوری، مقدار بیشتری از یون سدیم و مقدار کمتری از یون پتاسیم به شاخساره انتقال می‌یابد و باعث افت بیشتر در رشد گیاهچه‌ها می‌ شود. پیش‌تیمارسالیسیلیک‌اسید فاکتور ذخیره‌سازی سدیم را در سطوح بدون شوری یا شوری کم افزایش داد، بدین معنی که سدیم بیشتری که در ریشه نگهداری شد. تسریع در جذب آب، سرعت جوانه‌زنی زیادتر، تجمع سدیم کمتر و پتاسیم بیشتر در شاخساره، می‌تواند برخی از سازوکارهای تحمل به شوری در گیاهچه‌های پیش‌تیمارشده با سالیسیلیک‌اسید باشد.