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WATER RELATIONS AND IONIC COMPOSITION IN THE SEEDLINGS OF SOME NEWLY DEVELOPED AND CANDIDATE CULTIVARS OF WHEAT (*TRITICUM AESTIVUM* L.) UNDER SALINE CONDITIONS

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Abstract

Influence of salt stress on water relation parameters and pattern of ion accumulation was observed in 10 spring wheat cultivars, S-24, Lasani, Fsd-2008, Saher-2006, Inqlab-91, AARI-10, P.B-18, S.H-20, M.P-65, and G.A-20 at the seedling stage. The wheat cultivars were grown under saline (150 m*M*) and non-saline regimes (0 m*M*). Salt stress markedly reduced different water relation attributes such as leaf osmotic potential (Ψ_w), water potential (Ψ_s) and turgor potential (Ψ_p) of the seedlings of all wheat cultivars. However, relatively less decline in leaf Ψ_p recorded in cvs. S-24 and G.A-20 could be attributed to their higher degree of salt tolerance. Of different ions, root and leaf K^+ and Ca^{2+} concentrations reduced, while Na^+ concentration increased in all wheat cultivars under saline regime. K^+/Na^+ and Ca^{2+}/Na^+ ratios in both root and leaf of all cultivars also decreased under stress conditions. However, maintenance of higher Ca^{2+}/Na^+ and K^+/Na^+ ratios in cv. S-24, Inqlab-91 and G.A-20 in their roots and leaves compared to the other cultivars could also be related to their higher degree of salt tolerance. Of all wheat cultivars, S-24, Inqlab-91 and G.A-20 could be categorized as salt tolerant on the basis of water relation attributes and pattern of ion accumulation.

Introduction

Salinity of soil is contemplated as a major problem which negatively affects a multitude of metabolic processes of plants resulting in reduced growth and yield of most crops (Ahmad *et al*., 2007; Ashraf, 2009; Abro *et al*., 2009; Ahmad *et al*., 2011). The main metabolic processes hindered by salinity include ion uptake, osmotic adjustment, photosynthesis, protein/nucleic acid synthesis, enzymatic activities and hormonal balance (Gad & Kandil, 2011; Akram *et al*., 2011; Ahmad *et al*., 2012). Plant species respond differentially to salt stress because of various factors which include salt level of growth medium, exposure period of the stress, nature of plant genotype, plant's developmental stage and surrounding environment (Ashraf *et al*., 1987; Gorai *et al.*, 2011; Bahrani & Joo, 2011; Ashraf & Ashraf, 2012).

Water relation characteristics including osmotic potential, water potential and turgor potential are markedly affected due to saline stress. Reduced solute potential due to saline conditions significantly affects water uptake ability of plants (Munns, 2002) thereby causing water potential more negative which results in reduced growth of most plants (Khan, 2001; Cha-um *et al*., 2010; Eisa *et al*., 2012). To cope with these effects, different plant species adopt different mechanisms. Of these, osmotic adjustment is considered to be one of the key physiological strategies of plants to cope with salt stress (Farouk, 2011; Gorai *et al*., 2011). For osmotic adjustment, the cells may accumulate inorganic ions (K^+, Na^+ and Cl^-) and organic solutes (most commonly proline and glycinebetaine) to balance water potential of the cells and maintain their turgor. The osmotic adjustment occurs in both root and shoot when plants are under saline stress (Sanchez *et al*., 2004). Osmotic adjustment particularly in leaf is important for plant survival, because it facilitates leaf expansion by maintaining higher stomatal conductance (Westgate & Boyer, 1985; Cha-um *et al*., 2010; Eisa *et al*., 2011), which is considered necessary to sustain photosynthesis in the leaves under salt stress.

Higher accumulation of toxic ions such as Na^+ and Cl^- occurs in plants under saline conditions (Ashraf & Ahmad, 2000; Gorai *et al*., 2011; Heidari *et al*., 2011; Shahbaz & Zia, 2011). A number of studies on different plant species have shown that K^+ uptake is hindered by saline stress which results in decreased K^+/Na^+ ratio (Cha-um *et al*., 2010; Gandonou *et al*., 2011; Lenis *et al.*, 2011) which is harmful for plants, because K^+ is very important for the maintenance of ionic homeostasis in the cytosol (Szczerba *et al*., 2009), and turgor, osmotic adjustment and stomatal regulation (Chartzoulakis *et al*., 2006; Najafian *et al*., 2009; Kusvuran, 2012). The maintenance of high ratio of K^+/Na^+ in plant tissues can be used as an effective selection criterion for salt tolerance in plants (Reynolds *et al*., 2005).

The degree of salt tolerance in wheat differs at different growth stages, and seedling growth stage is reported as more sensitive than the other stages (Ashraf, 2009, Jenkins *et al.*, 2010; Shahbaz & Ashraf, 2013). Therefore, the present study was performed to examine the salt stress effect on physiological attributes at the seedling growth stage of 10 wheat genotypes including some candidate cultivars (AARI-10, P.B-18, M.P-65, G.A-20 and S.H-20) yet to be registered and some newly developed cultivars (S-24, Lasani, Saher-2006, Inqlab-91, Fsd-2008).

Materials and Methods

An experiment was conducted to examine the salt tolerance in 10 wheat cultivars, five newly developed (S-24, Lasani, Inqlab-91, Fsd-2008 and Saher-2006) and five candidate (AARI-10, S.H-20, P.B-18, G.A-20 and M.P-65) using ionic composition and leaf water relation attributes, osmotic potential, water potential and turgor potential, as selection criteria. Of these 10 cultivars, the seed of nine (Inqlab-91, Fsd-2008, Lasani, Saher-2006, P.B- 18, AARI-10, M.P-65, G.A-20 and S.H-20) was collected from the Ayub Agricultural Research Institute, Faisalabad, Pakistan and that of cv. S-24 from the Department of Botany, University of Agriculture, Faisalabad. The experiment was performed in the research area of the Botanical Garden, of the University of Agriculture, Faisalabad, Pakistan. All wheat cultivars were grown in plastic pots, each pot having diameter of 30 cm filled with 11 kg well washed river sand. Two salt (NaCl) levels (0 m*M* and 150 m*M*) prepared in full strength Hoagland's nutrient solution were applied. All pots were arranged in a completely randomized design with four replicates. The seedlings were thinned to four in each pot after germination and salt stress applied after 15 days of germination. Data for contents of different ions and water relation attributes were recorded when the seedlings were 45-day old.

Leaf water potential (Ψ_w): Early in the morning at 6:00 a.m. leaf water potential was measured using the 3rd leaf from each plant with a Scholander type water potential apparatus (Arimad-2-Japan).

Osmotic potential (Ψ_s): The same leaf used for the measurement of Ψ_w was kept in a freezer for one week at -21ºC. After extracting the sap from the frozen leaf material, osmotic potential determined with an osmometer (VAPRO, Model 5520, USA).

Turgor potential: As described by Nobel (1991) leaf turgor potential was calculated using the following equation:

$$\Psi p = \Psi w - \Psi s$$

Determination of Na^+, K^+ and Ca^{2+} in the leaf and root tissues: The root and leaf material was oven-dried at 65ºC and ground it to form a powder. A sample (0.1 g) of each tissue was digested in 2 ml sulfuric acid-hydrogen peroxide mixture as described by Wolf (1982). The amounts of Na^+, K^+ and Ca^{2+} in the digested samples were appraised with a flame photometer (PFP-7, Jenway Ltd).

Statistical analysis: Bartlett's test was performed on data of each variable by using the MSTAT computer package (MSTAT Development Team, 1989) to work out analysis of variance. All means within a variable were compared using the LSD test at 5% probability.

Results

In the present study, 10 newly developed and candidate wheat (*Triticum aestivum* L.) cultivars were assessed for salt tolerance on the basis of plant water relations and ionic contents at the seedling stage. Leaf water relation parameters including water potential (Ψ_w), osmotic potential (Ψ_s) and turgor potential (Ψ_p) were markedly affected due to saline stress. Leaf water potential (Ψ_w) and Ψ_s decreased (more -ve) significantly in all wheat cultivars at the seedling stage under salt stress (150 m*M*). Higher reduction in leaf Ψ_w was observed in cvs. Lasani and AARI-10, while less in cvs. S-24 and Fsd-2008 under salt stress. Cultivars M.P-65, AARI-10 and G.A-20 showed a maximum decrease in Ψ_s under saline conditions, and less reduction in Ψ_s was recorded in cvs. S-24, Saher-2006, Inqlab-91, Fsd-2008, Lasani and P.B-18. Leaf Ψ_p also decreased significantly in all wheat cultivars under salt stress. Of all wheat cultivars, the maximum reduction in leaf Ψ_p was recorded in Lasani and AARI-10, while cvs. S-24 and G.A-20 showed minimum leaf Ψ_p under saline conditions (Fig. 1; Table 1).

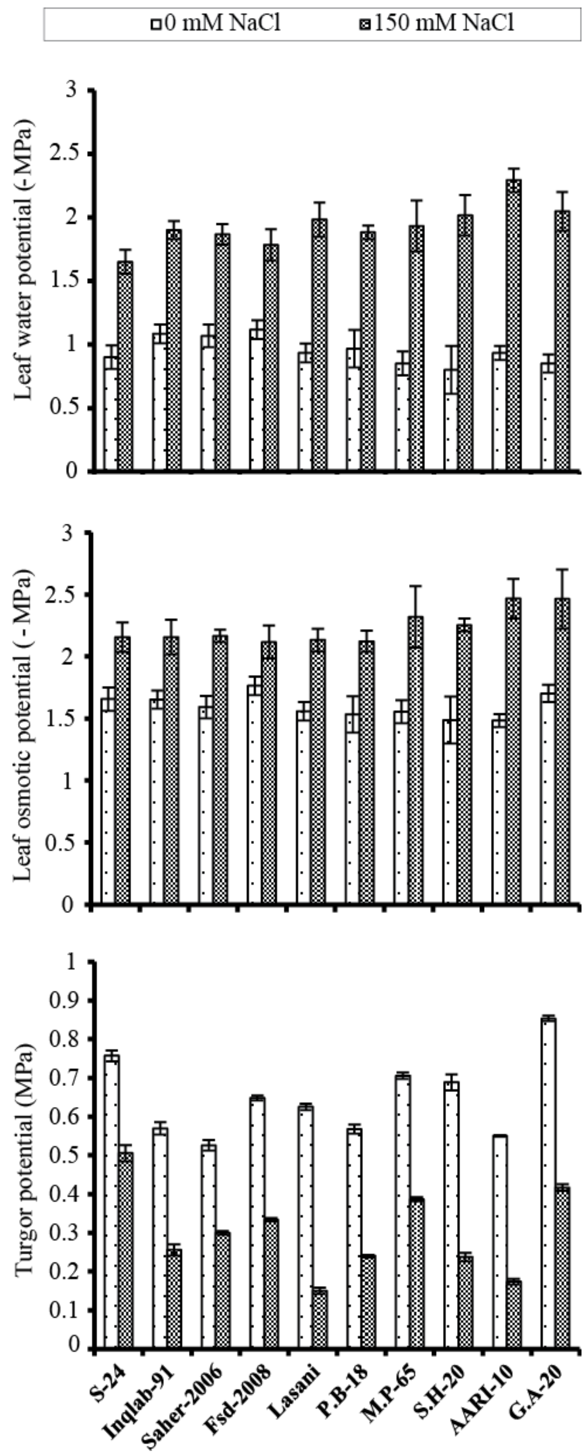

Fig. 1. Leaf water relation parameters of different cultivars of wheat (*Triticum aestivum* L.) as influenced by salt stress (150 m*M*) applied at the seedling stage (mean ± S.E.).

Table 1. Mean square values from analyses of variance of data for different ions and water relation parameters of 10 wheat cultivars under salt stress

Source	df	Ψw	Ψs	Ψp	
Salt stress (S)	1	14.573***	6.0786***	1.828***	-
Cultivars (Cv)	9	0.043 ns	0.0324 ns	0.059*	-
S × Cv	9	0.079**	0.0493 ns	0.010 ns	-
Error	40	0.026	0.0303	0.025	-
	df	**Leaf K^+**	**Root K^+**	**Leaf Na^+**	**Root Na^+**
Salt stress (S)	1	183.75**	3.75 ns	1560.6***	228.15***
Cultivars (Cv)	9	351.66***	4.704***	20.67**	10.046***
S × Cv	9	185.83***	10.890***	26.058***	16.483***
Error	40	25.00	0.925	129.62	1.212
	df	**Leaf Ca^{2+}**	**Root Ca^{2+}**	**Leaf K^+/Na^+**	**Root K^+/Na^+**
Salt stress (S)	1	21.6***	202.58***	1046.43***	2.049***
Cultivars (Cv)	9	4.337***	18.63***	5.007 ns	0.170***
S × Cv	9	4.079**	11.376**	12.178*	0.147***
Error	40	5.4125	2.075	5.0415	0.014
	df	**Leaf Ca^{2+}/Na^+**	**Root Ca^{2+}/Na^+**	**-**	**-**
Salt stress (S)	1	49.054***	6.795***	-	-
Cultivars (Cv)	9	0.2736*	0.1988**	-	-
S × Cv	9	0.705***	0.1755***	-	-
Error	40	0.117	0.0374	-	-

*, **, *** = significant at 0.05, 0.01, and 0.001 level, respectively
ns = non-significant

Data presented in Fig. 2 showed that leaf K^+ decreased significantly in all wheat cultivars under saline regimes. All cultivars showed differential behavior in response to salt stress. The maximum reduction in shoot K^+ concentration was recorded in cv. PB-18. A significant decrease in root K^+ concentration was observed in all wheat cultivars. Root K^+ concentration was higher in cvs. S-24, Saher-2006, Inqlab-91 and PB-18 as compared to that in the other cultivars. Overall, cv. PB-18, was the lowest in leaf and root K^+ accumulation. Root Na^+ increased in all wheat cultivars under saline conditions. However, increase in Na^+ concentration was greater in the leaves than that in the roots. Leaf Na^+ increased in all wheat cultivars under salt stress. Of all wheat cultivars, Inqlab-91, S.H-20 and G.A-20 showed higher values of leaf Na^+ .The maximum increase in root Na^+ was recorded in cvs. AARI-10 and M.P-65 and the minimum in cvs. Fsd-2008, Lasani and P.B-18 (Fig. 2). When salt stress applied at the seedling stage, root and shoot Ca^{2+} concentrations decreased significantly in all wheat cultivars. Decrease in Ca^{2+} was higher in the leaves than that in the roots. The maximum reduction in root Ca^{2+} was observed in cvs. S-24, Inqlab-91 and G.A-20, while the minimum in cvs. Saher-2006, Fsd-2008 and S.H-20 (Fig. 2; Table 1).

Root and leaf K^+/Na^+ ratios were markedly affected in all wheat cultivars under salt stress. Decrease in root K^+/Na^+ ratio was observed in all cultivars under saline stress. However, values of leaf K^+/Na^+ ratios were greater than those for root K^+/Na^+ ratios. Root K^+/Na^+ ratio was higher in cvs. S-24, M.P-65, S.H-20 and AARI-10 than those in the other wheat cultivars under saline environment. Leaf K^+/Na^+ ratio in different wheat cultivars showed an inconsistent pattern. However, under salt stress, cvs. S-24, Inqlab-91 and G.A-20 showed higher leaf K^+/Na^+ ratios. Although, leaf and root Ca^{2+}/Na^+ ratios decreased markedly under saline stress in all wheat cultivars, higher Ca^{2+}/Na^+ ratios in the roots were recorded in wheat cvs. Saher-2006, M.P-65, S.H-20 and AARI-10, while the leaf Ca^{2+}/Na^+ were higher in cvs. S-24, Inqlab-91 and G.A-20 (Fig. 3).

Discussion

Soil water status is considered as the main factor which affects growth and development in plants subjected to saline stress (Rampino *et al*., 2006; Dulai *et al*., 2011; Kanwal *et al*., 2011; Kausar & Shahbaz, 2013). Low water potential of the saline grown medium causes accumulation of solutes in the cells, which lowers the cell osmotic potential. The reduced cellular osmotic potential is necessary for osmoregulation i.e., maintenance of turgor pressure (Navarro *et al*., 2003; Szczerba *et al*., 2009; Cha-um *et al*., 2010). Osmoregulation is considered as an important mechanism for the normal cell functioning (Taiz & Zeiger, 2010) because maintenance of water status in plant is an essential phenomenon for normal plant growth and development under stressful environments (Ali & Ashraf, 2011). In the present study, all wheat cultivars maintained Ψw to a more negative level under salt stress compared with that at non-saline conditions (Fig. 1). This is a common plant response to salinity which has been widely reported in different reports (Suárez & Medina, 2008; Gorai *et al*., 2011; Kusvuran, 2012). In the present study, cvs. S-24, M.P-65 and G.A-20 showed less decrease in turgor potential under salt stress as compared to the other wheat cultivars. This indicates high tolerance of these cultivars to salinity as has been reported earlier in different plant species (Farouk, 2011; Heidari *et al*., 2011; Jabeen & Ahmad, 2012; Eisa *et al*., 2012).

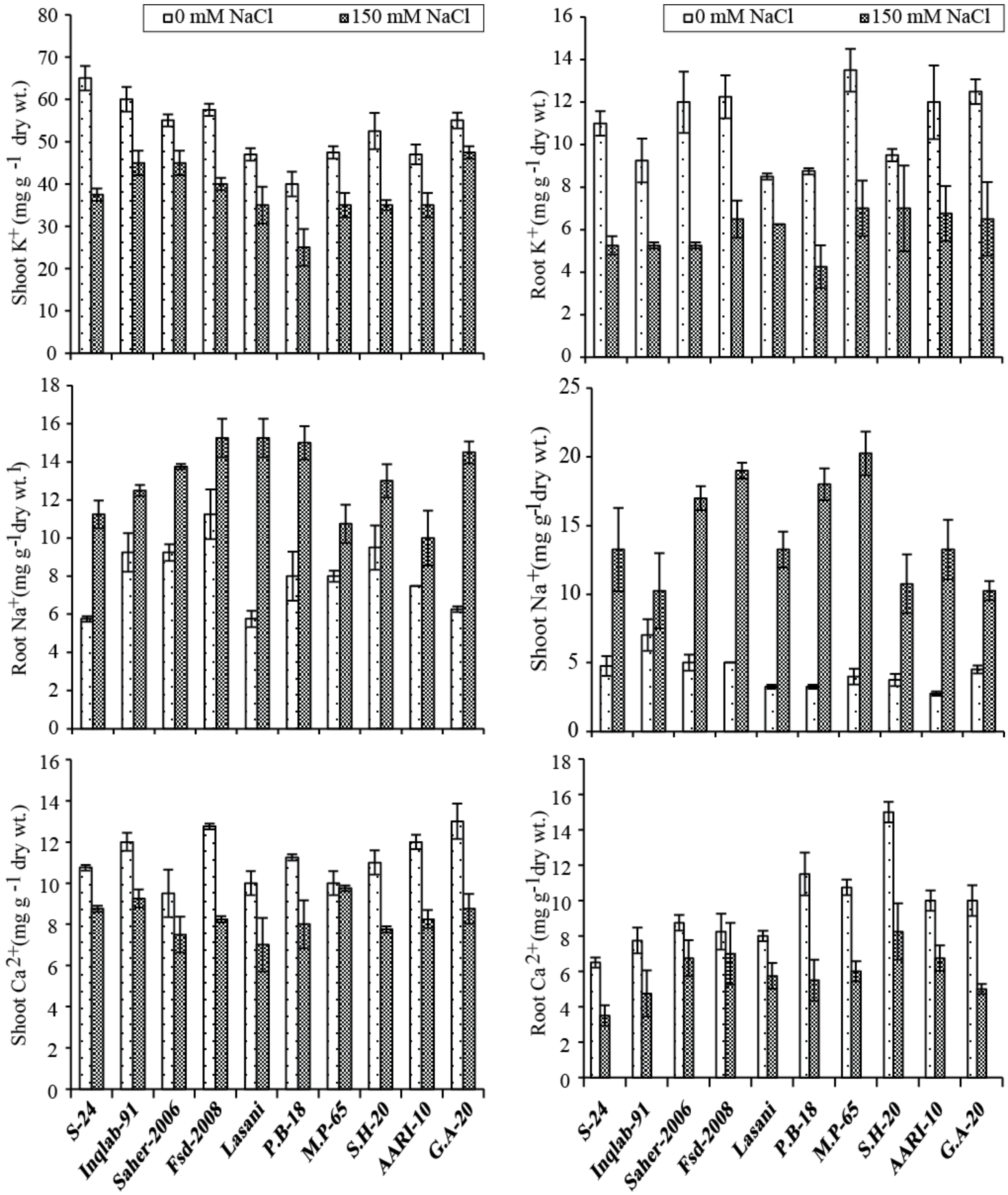

Fig. 2. Shoot and root K^+, Na^+ and Ca^{2+} of different cultivars of wheat (*Triticum aestivum* L.) as influenced by salt stress (150 m*M*) applied at the seedling stage (mean ± S.E.).

Pattern of ion accumulation, transport and their distribution in different plant parts and within the cell is a vital indicator for salt tolerance mechanism in most plants (Ashraf, 2004; Munns & Tester, 2008; Akram *et al*., 2009; Akram & Ashraf, 2011). Excessive accumulation of ions in salt-stressed plants can decline leaf functions and ionic imbalance, and cause ion toxicity (Yildirim *et al*., 2009). Exclusion of Na^+ and Cl^- and maintenance of high K^+/Na^+ ratios in the tissues are among the important aspects of mechanisms of salt tolerance in most plants (Zheng *et al*., 2008; Shahbaz *et al*., 2011). In this study, salt stress caused a marked increase in Na^+ concentration in the roots and leaves of all wheat cultivars under salt stress. However, leaf Na^+ concentration was greater than root Na^+ in almost all wheat cultivars and cvs. AARI-10 and M.P-65 showed maximum concentration of root Na^+. In contrast, leaf Na^+ concentration was higher in cvs. Inqlab-91, S.H-20 and G.A-20. Generally, it has been observed that when plants grow under saline environments, they absorb higher amount of Na^+, but antagonistically lower amount of K^+ and Ca^{2+}. For the maintenance of cell membrane integrity and functioning, a reasonable amount of K^+ and Ca^{2+} is required by plants grown under saline stress (Wenxue *et al*., 2003; Kader & Lindbeg, 2010). Adequate maintenance of K^+ in tissues is dependent upon the selective uptake of K^+, and cellular compartmentation and distribution of K^+ and Na^+ ions in shoots (Siringam *et al*., 2011). However, maintenance of high K^+/Na^+ ratio under saline environment is considered as an important salt tolerance selection criterion (Chinnusamy *et al*., 2005; Siringam *et al*., 2011). Both root and leaf K^+/Na^+ and Ca^{2+}/Na^+ ratios decreased consistently in all wheat cultivars. However, these ionic ratios were greater in shoots than those in roots. High ratios of K^+/Na^+ and Ca^{2+}/Na^+ in wheat cvs. S-24, Inqlab-91 and G.A-20 could have played an important role in their tolerance to salt (Ashraf & Khanum, 1997; Ashraf & Orooj, 2006).

Overall, salt tolerance in the 10 wheat cultivars was found to be linked to high leaf turgor potential and K^+/Na^+ and Ca^{2+}/Na^+ ratios in plant tissues. So, newly developed wheat cultivars S-24, Inqlab-91 and G.A-20 were more salt tolerant than the other cultivars examined in this study on the basis of plant water relation parameters and ionic contents measured at the seedling stage.

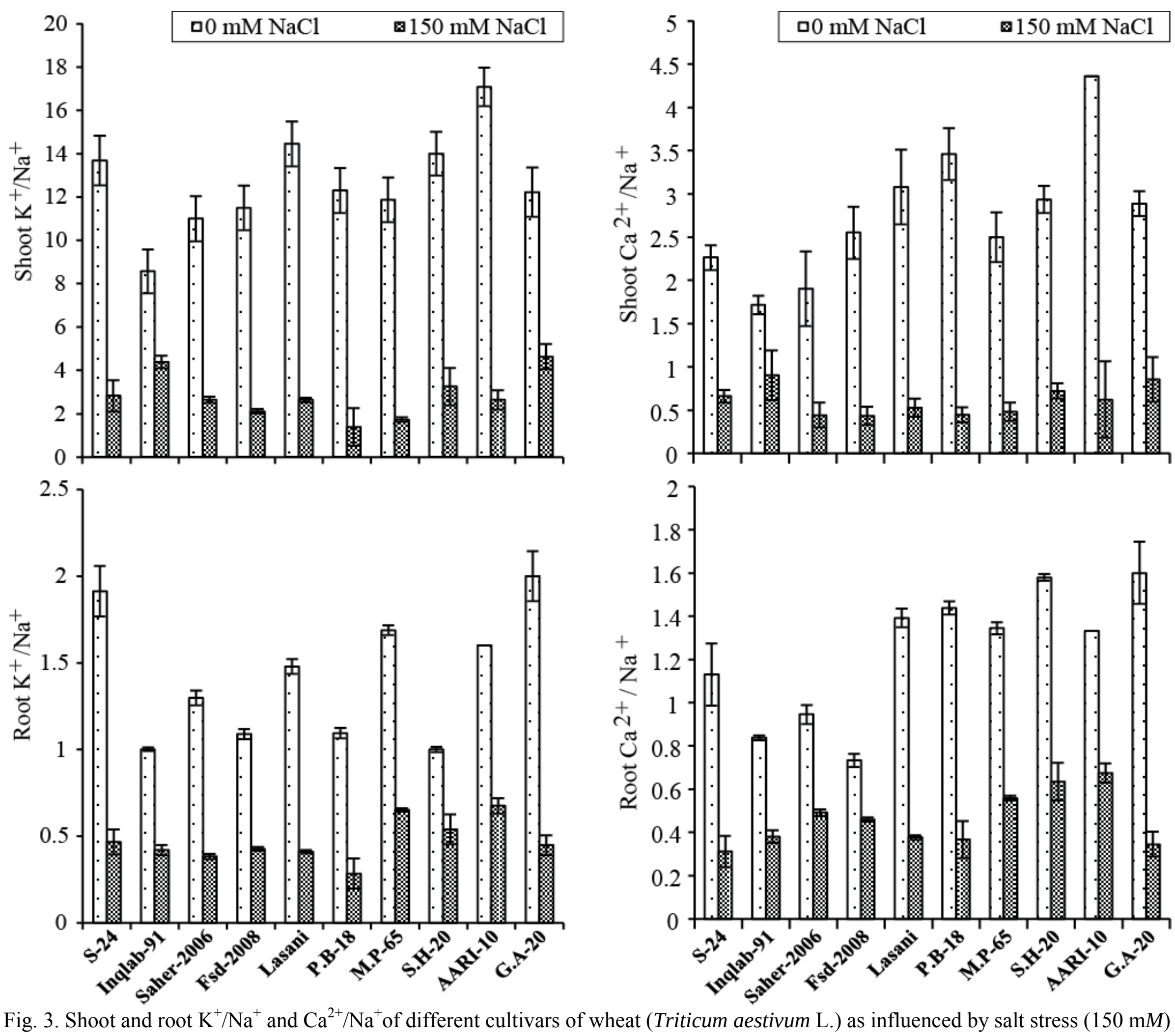

Fig. 3. Shoot and root K^+/Na^+ and Ca^{2+}/Na^+ of different cultivars of wheat (*Triticum aestivum* L.) as influenced by salt stress (150 m*M*) applied at the seedling stage (mean ± S.E.).

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References

Abro, S.A., A.R. Mahar and A.A. Mirbahar. 2009. Improving yield performance of landrace wheat under salinity stress using on-farm seed priming. *Pak. J. Bot*., 41(5): 2209-2216.

Ahmad, M.S.A., F.J. Khan and M. Ashraf. 2007. Iso-osmotic effect of NaCl and PEG on growth, cations and free proline accumulation in callus tissue of two indica rice (*Oryza sativa* L.) genotypes. *Plant Growth Regul.,* 53: 53-63.

Ahmad, M., M. Munir, A. Shahzad, M.S. Masood and M. Iqbal. 2011. Evaluation of bread wheat genotypes for salinity tolerance under saline field conditions. *Afr. J. Biotechnol.*, 10: 4086-4092.

Ahmad, P., K. Hakeem, A. Kumar, M. Ashraf and N.A. Akram. 2012. Salt-induced changes in photosynthetic activity and oxidative defense system of three cultivars of mustard (*Brassica juncea* L.). *Afr. J. Biotechnol*., 11: 2694-2703.

Akram, M.S., M. Ashraf and N.A. Akram. 2009. Effectiveness of potassium sulfate in mitigating salt-induced adverse effects on different physio-biochemical attributes in sunflower (*Helianthus annuus* L.). *Flora*, 204(6): 471-483.

Akram, N.A. and M. Ashraf. 2011. Pattern of accumulation of inorganic elements in sunflower (*Helianthus annuus* L.) plants subjected to salt stress and exogenous application of 5-aminolevulinic acid. *Pak. J. Bot*., 43(1): 521-530.

Akram, N.A., M. Ashraf and F. Al-Qurainy. 2011. Aminolevulinic acid induced changes in yield and seed-oil characteristics of sunflower (*Helianthus annuus* L.) under salt stress. *Pak. J. Bot*., 43: 2845-2852.

Ali, Q. and M. Ashraf. 2011. Induction of drought tolerance in maize (*Zea mays* L.) due to exogenous application of trehalose: growth, photosynthesis, water relations and oxidative defence mechanism. *J. Agron. Crop Sci*., 1: 1-14.

Ashraf, M. 2004. Some important physiological selection criteria for salt tolerance in plants. *Flora,* 199(5): 361-376.

Ashraf, M. 2009. Biotechnological approach of improving plant salt tolerance using antioxidants as markers. *Biotechnol. Adv*., 27: 84-93.

Ashraf, M.A. and M. Ashraf. 2012. Salt-induced variation in some potential physiochemical attributes of two genetically diverse wheat (*Triticum aestivum* L.) cultivars: photosynthesis and photosystem II efficiency. *Pak. J. Bot*., 44(1): 53-64.

Ashraf, M. and A. Khanum. 1997. Relationship between ion accumulation and growth in two spring wheat lines differing in salt tolerance at different growth stages. *J. Agron. Crop Sci.* 178: 39-51.

Ashraf, M. and A. Orooj. 2006. Salt stress effects on growth, ion accumulation and seed oil concentration in an arid zone traditional medicinal plant ajwain (*Trachyspermum ammi* [L.] Sprague). *J. Arid Environ*., 64: 209-220.

Ashraf, M. and S. Ahmad 2000. Influence of sodium chloride onion accumulation, yield components and fibre characteristics in salt-tolerant and salt-sensitive lines of cotton (*Gossypium hirsutum* L.). *Field Crops Res*., 66**:** 115-127.

Ashraf, M., T. McNeilly and A.D. Bradshaw. 1987. Selection and heritability of tolerance to sodium chloride in 4 forage species. *Crop Sci*., 27: 232-243.

Bahrani, A. and M.H. Joo. 2011. Response of some wheat (*Triticum aestivum* L.) genotypes to salinity at germination and early seedling growth stages. *World Appl. Sci. J*., 13: 887-897.

Chartzoulakis, K., G. Psarras, S. Vemmos, M. Loupassaki and M. Bertaki. 2006. Response of two olive cultivars to salt stress and potassium supplement. *J. Plant Nutri.,* 29: 2063-2078.

Cha-um, S., K. Siringamb, N. Juntawongb and C. Kirdmanee. 2010. Water relations, pigment stabilization, photosynthetic abilities and growth improvement in salt stressed rice plants treated with exogenous potassium nitrate application. *Int. J. Plant Produc*., 4(3): 1735-8043.

Chinnusamy, V., A. Jagendorf and J.K. Zhu. 2005. Understanding and improving salt tolerance in plants. *Crop Sci*., 45: 437-448.

Dulai, S., I. Molnár and M.M. Láng. 2011. Changes of photosynthetic parameters in wheat/barley introgression lines during salt stress. *Acta Biol. Szegediensis*, 5(1): 73-75.

Eisa, S., S. Hussin, N. Geissler and H.W. Koyro. 2012. Effect of NaCl salinity on water relations, photosynthesis and chemical composition of quinoa (*Chenopodium quinoa* Willd.) as a potential cash crop halophyte. *AJCS*, 6(2): 357-368.

Farouk, S. 2011. Osmotic adjustment in wheat flag leaf in relation to flag leaf area and grain yield per plant. *J. Stress Physiol. Biochem*., 7: 117-138.

Gad, N. and H. Kandil. 2011. Maximizing the tolerance of wheat plants to soil salinity using cobalt. I. growth and mineral composition. *J. Appl. Sci. Res*., 7: 1569-1574.

Gandonou, C.B., F. Bada, S.L. Gnancadja, J. Abrini and N.S. Senhaji. 2011. Effects of NaCl on Na^+, Cl^- and K^+ ions accumulation in two sugarcane (*Saccharum* spp.) cultivars differing in their salt tolerance. *Int. J. Plant Physiol. Biochem*., 3(10): 155-162.

Gorai, M., M. Ennajeh, H. Khemira and M. Neffati. 2011. Influence of NaCl-salinity on growth, photosynthesis, water relations and solute accumulation in *Phragmites australis*. *Acta Physiol. Plant*., 33: 963-971.

Heidari, A., M. Toorchi, A. Bandehagh and M. Shakiba. 2011. Effect of NaCl stress on growth, water relations, organic and inorganic osmolytes accumulation in sunflower (*Helianthus annuus* L.) lines. *Universal J. Environ. Res. Technol*., 3: 351-362.

Jabeen, N. and R. Ahmad. 2012. Improvement in growth and leaf water relation parameters of Sunflower and Safflower plants with foliar application of nutrient solutions under salt stress. *Pak. J. Bot*., 44(4): 1341-1345.

Jenkins, S., G. Edward, B. Lennard and Z. Rengel. 2010. Impacts of water-logging and salinity on puccinellia (*Puccinellia ciliata*) and wheat grass (*Thinnopyrum ponticum*) zonation on salt land with a shallow-water table, plant growth and Na^+ and K^+ concentrations in the leaves. *Plant Soil*, 329: 91-104.

Kader, M.A. and S. Lindberg. 2010. Cytosolic calcium and pH signaling in plants under salinity stress. *Plant Signal. Behav*., 5(3): 233-238

Kanwal, H., M. Ashraf and M. Shahbaz. 2011. Assessment of salt tolerance of some newly developed and candidate wheat (*Triticum aestivum* L.) cultivars using gas exchange and chlorophyll fluorescence attributes. *Pak. J. Bot*., 43(6): 2693-2699.

Kausar, F. and M. Shahbaz. 2013. Interactive effect of foliar application of nitric oxide (NO) and salinity on wheat (*Triticum aestivum* L.). *Pak. J. Bot*., 45(SI): 67-73.

Khan, M.A. 2001. Experimental assessment of salinity tolerance of *Ceriops tagal* seedlings and samplings from the Indus delta, Pakistan. *Aquat. Bot*., 70: 259-268.

Kusvuran, S. 2012. Effects of drought and salt stresses on growth, stomatal conductance, leaf water and osmotic potentials of melon genotypes (*Cucumis melo* L.). *Afr. J. Agric. Res.*, 7(5): 775-781.

Lenis, J.M., M. Ellersieck, D.G. Blevins, D.A. Sleper, H.T. Nguyen, D. Dunn, J.D. Lee and J. G. Shannon. 2011. Differences in ion accumulation and salt tolerance among glycine accessions. *J. Agron. Crop Sci*., 197: 302-310.

Munns, R. 2002. Comparative physiology of salt and water stress. *Plant Cell Environ*., 25: 239-250.

Munns, R. and M. Tester. 2008. Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol*., 59: 651-681.

Najafian, S., M. Khoshkhui, V. Tavallali and M.J. Saharkhiz. 2009. Effect of salicylic acid and salinity in Thyme (*Thymus vulgaris* L.): Investigation on changes in gas exchange, water relations, and membrane stabilization and biomass accumulation. *Aust. J. Basic Appl. Sci*., 3(3): 2620-2626.

Navarro, J.M., C. Garrido, V. Martínez and M. Carvajal. 2003. Water relations and xylem transport of nutrients in pepper plants grown under two different salts stress regimes. *Plant Growth Regul*., 41: 237-245.

Nobel, P.S. 1991. Physicochemical and environmental plant physiology. Academic Press, San Diego.

Rampino, P., S. Pataleo, C. Gerardi, G. Mita and C. Perrotta. 2006. Drought stress response in wheat: physiological and molecular analysis of resistant and sensitive genotypes. *Plant Cell Environ*., 29: 2143-2152.

Reynolds, M.P., A.M. Kazi and M. Sawkins. 2005. Prospects for utilizing plant-adaptive mechanisms to improve wheat and other crops in drought and salinity-prone environments. *Ann. Appl. Biol.,* 146: 239-259.

Sánchez, F.J., E.F. de Andrés, J.L. Tenorio and L. Ayerbe. 2004. Growth of epicotyls, turgor maintenance and osmotic adjustment in pea plants (*Pisum sativum* L.) subjected to water stress. *Field Crops Res*., 86(1): 81-90.

Shahbaz, M. and B. Zia. 2011. Does exogenous application of glycinebetaine through rooting medium alter rice (*Oryza sativa* L.) mineral nutrient status under saline conditions? *J. Appl. Bot. Food Qual*., 84: 54-60.

Shahbaz, M. and M. Ashraf. 2013. Improving salinity tolerance in cereals. *Crit. Rev. Plant Sci*., 32: 237-249.

Shahbaz, M., M. Ashraf, N.A. Akram, A. Hanif, S. Hameed, S. Joham and R. Rehman. 2011. Salt-induced modulation in growth, photosynthetic capacity, proline content and ion accumulation in sunflower (*Helianthus annuus* L.). *Acta Physiol. Plant*., 10: 639-649.

Siringam, K., N. Juntawong, S. Cha-um and C. Kirdmanee. 2011. Salt stress induced ion accumulation, ion homeostasis, membrane injury and sugar contents in salt-sensitive rice (*Oryza sativa* L. spp. *indica*) roots under isoosmotic conditions. *Afr. J. Biotechnol.*, 10(8): 1340-1346.

Suárez, N. and E. Medina. 2008. Salinity effects on leaf ion composition and salt secretion rate in *Avicennia germinans* (L.) L. *Braz. J. Plant Physiol*., 20: 131-140.

Szczerba, M.W., D.T. Britto and H.J. Kronzucker. 2009. K^+ transport in plants: Physiology and molecular biology. *J. Plant Physiol*., 166: 447-466.

Taiz, L. and E. Zeiger. 2010. *Plant Physiology*. 5th ed, ISBN 978-0-87893-511-6. Sinauer Associates Inc. Publishers, Sunderland.

Wenxue, W., P.E. Bilsborrow, P. Hooley, D.A. Fincham, E. Lombi and B.P. Forster. 2003. Salinity induced differences in growth, ion distribution and partitioning in barley between the cultivar maythorpe and its derived mutant Golden Promise. *Plant Soil*, 250: 183-191.

Westgate, M.E. and J.S. Boyer. 1985. Osmotic adjustment and the inhibition of leaf, root, stem, and silk growth at low water potentials in maize. *Planta*, 164: 540-549.

Wolf, B. 1982. A comprehensive system of leaf analysis and its use for diagnosing crop nutrient status. *Commun. Soil Sci. Plant Anal*., 13: 1035-1059.

Yildirim, E., H. Karlidag and M. Turan. 2009. Mitigation of salt stress in strawberry by foliar K, Ca and Mg nutrient supply. *Plant Soil Environ*., 55: 213-221.

Zheng, Y., A. Jiac, T. Ning, J. Xud, Z. Lib and G. Jiang. 2008. Potassium nitrate application alleviates sodium chloride stress in winter wheat cultivars differing in salt tolerance. *J. Plant Physiol*., 165: 1455-1465.

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