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Effect of salinity on wheat (*Triticum aestivum* L.) grain yield, yield components and ion uptake

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Abstract

Crops growing in salt-affected soils may suffer from physiological drought stress, ion toxicity, and mineral deficiency. A pot study was conducted in 2004-2005 in the Aghala area (northern Iran) to study the effect of different salinity levels, i.e. EC_e= 3 (control), 8, 12 and 16 dS m^{-1} on wheat grain, yield components and leaf ion uptake of four Iranian wheat genotypes, i.e. Kouhdasht, Atrak, Rasoul and Tajan. Treatments were replicated three times in a completely randomized design in a factorial arrangement. Desired salinity levels were obtained by mixing adequate NaCl before filling the pots. Soil water was maintained at 70% of available water holding capacity. Results revealed that Kouhdasht and Tajan showed highest and lowest grain yield and its components as compared to other cultivars at different salinity levels. Leaf Na^+ and Cl^- concentrations of all genotypes increased significantly with increasing soil salinity, with the highest concentrations in Tajan, followed by Rasoul, Atrak and Kouhdasht cultivars, respectively. Highest leaf K^+ concentration and K^+: Na^+ ratio were observed in Kouhdasht cultivar, followed by Atrak, Rasoul and Tajan, respectively. Therefore, Kouhdasht and Atrak were identified as the most salt-tolerant genotypes as compared to two other wheat genotypes.

***Keywords*:** Abiotic stresses; Plant ecophysiology; Stress physiology; Semi-arid agriculture

1. Introduction

Abiotic stress is the most harmful factor concerning the growth and productivity of crops worldwide (Mane *et al*., 2011). Salinity is one of the major abiotic stresses that adversely affect crop productivity and quality (Chinnusamy *et al*., 2005). The United Nations Environment Program (UNEP) estimates that approximately 50% of cropland in the world is salt-stressed (Flowers and Yeo, 1995). On average, 20% of all irrigated lands are affected by salts (Yeo, 1999), but this figure increases to more than 30% in countries such as Egypt, Argentina and Iran (Zink, 2003).

Adverse effects of salinity on plant growth may be due to ion cytotoxicity (mainly due to Na^+, Cl^-, and SO_4^{2-}) and osmotic stress (Zhu, 2002). Based on plants capacity to grow on high salt medium, they can be classified into two groups, i.e. halophytes and glycophytes. Halophytes are tolerant to high NaCl concentrations (Zhu, 2001a).

They generally accumulate Na^+ and Cl^- in vacuoles and synthesize organic osmolytes in the cytoplasm, which facilitates water uptake into the plant and enhances turgor-driven growth at low to moderate salinity levels (Bell and O'Leary, 2003). By contrast, with glycophytes, salinity imposes ionic stress, osmotic stress, and secondary stresses such as nutritional disorders and oxidative stress (Zhu, 2001a).

Wheat is moderately tolerant to salt with threshold without yield loss at 6 dS m^{-1} (Mass and Hoffmann, 1977; Munns *et al*., 2006) and with yield 50% loss at 13 dS m^{-1} (Mass and Hoffmann, 1977). Salinity has inhibitory effects on wheat phenological aspects such as leaf number, leaf rate expansion (El-Hendawy *et al*., 2005), root growth rate (Neumann, 1995b), root/shoot ratio (El-Hendawy *et al*., 2005) and total dry matter yield (Pessarakli and Huber, 1991).

A number of characteristics, reviewed and summarized by Colmer *et al*. (2005a), contribute to salt tolerance in wheat. Foremost among salt-specific traits is the ability to maintain low Na^+ and high K^+ concentrations in leaves, and K^+: Na^+ discrimination is also correlated with salt tolerance within wheat (Gorham, 1990a; Tyerman and Skerrett, 1999; Munns and James, 2003). There is

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little genetic variation in Cl^- concentration within wheat leaves (Husain *et al*., 2004).

The sensitivity of some crops to salinity has been attributed to the inability to keep Na^+ and Cl^- out of the transpiration stream. For many glycophytes, but not all, differences in salt tolerances between genotypes have been closely associated with reduced uptake and accumulation of Na^+ and/or Cl^- ions at the whole plant (Lee *et al*., 2005; Tester and Davenport, 2003; Francois and Mass, 1994), shoot and leaf level (Francois and Mass, 1994). In such cases, genetic diversity in the trait of Na^+ and Cl^- exclusion could be useful selection traits to screen wheat genotypes for salinity tolerance (El-Hendawy, 2004).

Munns *et al*. (2006) found that wheat genotypes with the lowest Na^+ concentrations produced more dry matter than genotypes with high Na^+ concentrations. Moreover, there low-Na^+ genotypes had fewer injured leaves, and a higher proportion of living to dead leaves.

Several studies have been carried out with different wheat genotypes to look for tolerance to salinity in Iran and eventually a few genotypes, i.e. Alvand, Roshan, Sorkh-tokhmeh, Sholeh, Tabasi, Kavir, Mahoti and Mahdavi were found to be salt-tolerant and consequently proposed to farmers (reviewed by Cheraghi, 2004). However, to our knowledge no work has been done to investigate the response of the wheat cultivars that were studied for our experiments, i.e. Kouhdasht, Rasoul, Tajan and Atrak to soil salinity stress. Therefore, the aim of the present study was to quantify effects of different salinity levels on grain yield, yield components and leaf ion concentrations of these wheat genotypes.

2. Materials and Methods

2.1 Site Description

A pot study was conducted in 2004-2005 in the Aghala area of northern Golestan province (37° 07' N, 54° 07' E) which is located in north of Iran. A semi-arid climate prevails in the area. Mean annual rainfall in Aghala is 386 mm, whereas mean maximum and minimum temperatures are 37.5°C and 1.1°C, respectively. As measured with a US Class A evaporation pan, mean annual evapotranspiration is 1445 mm (Asgari, 2001). Golestan province is considered as a major agricultural region of Iran. It consists of vast area of salt-affected soils in the northern parts due to shallow and brackish groundwater and/or high evapotranspiration (Kiani *et al*., 2005). In Aghala plain, except marginal perch of land in the south near Gorganrud River (that works as a natural drain), most agricultural lands, especially in the north suffer from salinity (Asgari, 2008). Therefore, we situated experimental area in the south, to be able to use normal (non-saline) soil samples and then add calculated amounts of NaCl to create desired levels of saline soils.

2.2 Treatments and Measurements

Treatment combinations included four salinity levels, i.e. 3 (control), 8, 12 and 16 dS m^{-1} and four wheat genotypes. Some properties of the selected wheat genotypes are summarized in Table1. To characterize soil conditions, fifteen spots were randomly selected on an agricultural field (with 4 hectares in size). In each spot, 2 to 3 sub-samples of approximately 0.5-0.6 kg (wet) weight were taken from the top 0-30 cm using a 4 cm diameter Edelman auger. Specific spot sub-samples were thoroughly mixed to obtain a composite soil sample for each location. Some physico-chemical properties of the soil at the study site are presented in Table 2. Prior to filling test pots (height: 0.33 m; diameter: 0.20 m), NaCl was mixed with the soil to obtain the desired salinity levels. The quantity of NaCl required obtaining a given salinity level was calculated as Eq. 1 (USDA, 1954):

$$\text{g NaCl per kg soil} = \text{TSS} \times \text{equivalent weight of NaCl} \times \text{SP}/1000 \times 100 \quad \text{Eq. 1}$$

where TSS is total soluble salts, SP is saturation percentage, i.e. moisture percentage of a saturated soil paste on a dry weight basis, whereby the equivalent weight of NaCl was taken as 58.5 meq l^{-1}.

Table.1 Some properties of wheat genotypes used in the experiment (Kalateh *et al*., 2001)

Properties \ Genotypes	Tajan	Atrak	Rasoul	Kouhdasht
Seed colour	red	red	white	white
Plant height (cm)	90-95	85-95	90-95	92-104
Grain yield (ton ha^{-1})	5-7	4-6	4-6	4-6
Protein percent (per grain)	13	12.3	12	11.5
Lodging	tolerant	tolerant	tolerant	tolerant
Stripe rust (*Puccinia striiformis)*	semi- tolerant	semi-sensitive	semi-sensitive	semi- tolerant
Fusarium head blight (*Fusarium graminearum*)	semi-sensitive	semi- tolerant	semi- tolerant	semi- tolerant
Sowing date	December	December	December	December
Sowing rate (kg ha^{-1})	130-150	120-140	130-150	135-160

Fertilizers were applied at 120: 60: 60 kg ha^{-1} NPK as urea, single super phosphate and potassium sulfate, respectively. Ten seeds were sown in each pot with 5 lit pot^{-1} soil. After germination, three uniform seedlings were selected and allowed to grow whereas the rest was uprooted and discarded. Soil water was maintained at 70% of available water holding capacity. At grain maturity, all plants from each pot were harvested. At grain maturity, numbers of spikes, spikelets, productive tillers and spike lengths and TGW, grain yield, harvest index and straw yield (weight) were recorded. Wheat leaves were dried at 70 °C and then were digested with 1 NHCl for 24 hours at 40 °C, then shaken for 1.5 hours, and filtered manually. Na^+ and K^+ concentrations were determined by flame photometry (Jenway PFP-7, Essex, UK), whereas Cl^- was measured with a coulometric chloride analyzer (Corning 926, Essex, U.K.).

Table. 2 Some physico-chemical properties of the sampling soil

Soil sampling depth (cm)	Soil texture	Clay 0-2 µm (g kg^{-1})	Silt 2-50 µm (g kg^{-1})	Sand 50-2000 µm (g kg^{-1})	OM (g kg^{-1})	Saturated percent (mass%)	Field capacity (mass%)	ECe (dS m^{-1})	pH
0-30	Si-L	14	72	14	1.52	42	24.0	3.0	7.8
30-60	Si-C-L	33	59	8	-	49	28.5	3.9	8.0
60-90	Si-C-L	33	61	6	-	53	28.8	6.2	7.9

OM is organic matter content (not measured for 30-60 and 60-90 cm depths);
EC_e is electrical conductivity on a saturation extract at 25 °C;
Si-L and Si-C-L are silt loam and silty clay loam soils, respectively.

2.4 Statistical Analysis

Completely randomized design (Steel and Torrie, 1980) in factorial arrangement data thus obtained were statistically analyzed using SPSS computer software (version 12.0). Treatment means were compared using Duncan's Multiple Range Test (Duncan, 1955). A p level of 0.05 was considered in all statistical tests, except when otherwise mentioned.

3. Results

3.1 Grain yield

Grain yield of all wheat genotypes significantly decreased with increasing salinity levels (Fig.1a). At relatively low salinity level (LS), Kouhdasht showed significantly higher grain yield than the other genotypes. At relatively moderate salinity (MS) and high salinity (HS) levels, yield differences between genotypes were more pronounced than at LS. Kouhdasht showed significantly higher grain yield than the other genotypes, whereas grain yield of Atrak was significantly higher than that of Rasoul and Tajan. Grain yield differences between the latter two genotypes were not significant at MS and HS.

3.2 Thousand Grain Weight (TGW)

TGW of all wheat genotypes significantly decreased with increasing salinity level (Fig.1b). At LS, highest TGW was observed for Kouhdasht: this value was significantly higher than for the other genotypes. Non-significant differences were observed in TGW of Tajan and Atrak, whereas Rasoul showed consistently the lowest TGW values. At MS and HS, more pronounced differences in TGW were observed compared to LS. Kouhdasht showed significantly higher TGW than the other genotypes. Non-significant differences were observed in TGW of Rasoul and Tajan at MS and HS.

3.3 Number of Spikelets per Spike (NSS)

NSS of all wheat genotypes was decreased with increasing salinity levels (Fig. 1c). Except for Tajan, LS caused a non-significant decrease in NSS of all wheat genotypes as compared to control conditions. At MS and HS, Tajan showed significantly lower NSS values compared to Kouhdasht and Atrak. Kouhdasht showed highest NSS compared to the other wheat genotypes.

3.4 Spike Length

Spike length of all wheat genotypes was decreased significantly by applying different levels of salinity as compared to control treatment (Fig. 1d). At LS, Kouhdasht showed significantly higher spike length than the other wheat genotypes. At MS and HS, Tajan showed significantly lower spike length than the other three wheat genotypes, whereas Kouhdasht showed the significantly highest spike length.

3.5 Number of Tillers per Plant (NTP)

NTP of all wheat genotypes significantly decreased with increasing salinity levels (Fig. 1e). NTP of Tajan and Rasoul significantly decreased at LS compared to control. Compared to LS, NTP was significantly reduced at MS and HS for all wheat genotypes. Non-significant differences in NTP were observed between Kouhdasht and Atrak and also between Rasoul and Tajan at both MS and HS.

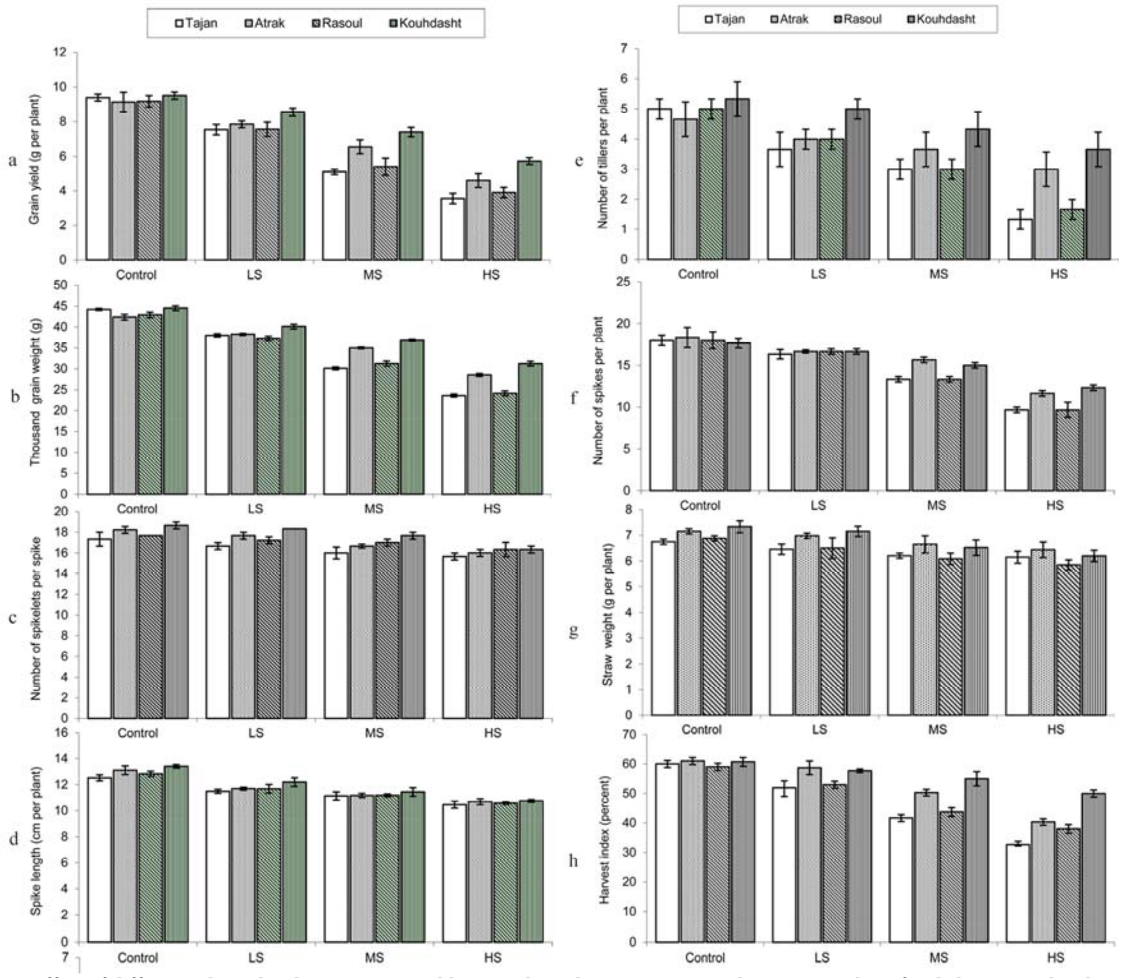

Fig. 1. Effect of different salinity levels on a) grain yield (g per plant); b) 1000 grain weight (g); c) number of spikelets per spike; d) spike length (cm per plant); e) tiller numbers per plant; f) spikes number per plant; g) straw weight (g); and h) harvest index (%). LS, MS and HS denote relatively low, moderate and high salinity level, respectively; error bars indicate standard deviation.

3.6 Number of Spikes per Plant (NSP)

NSP of all wheat genotypes decreased significantly with increasing salinity levels (Fig. 1f). Non-significant differences were observed for NSP for all wheat genotypes at both control and LS. At MS and HS, Kouhdasht and Atrak cultivars showed significantly higher NSP values than Rasoul and Tajan cultivars. Rasoul and Tajan showed similar NSP.

3.7 Straw Weight

Straw weight of all wheat genotypes decreased with increasing salinity levels (Fig. 1g). At LS, Atrak showed significantly highest straw weight compared to the other genotypes. Non-significant changes in straw weight of the other wheat genotypes were observed at LS as compared to control. At MS and HS, Tajan had significantly lowest straw weight as compared to that obtained by other cultivars.

3.8 Harvest Index (HI)

HI of all wheat genotypes significantly decreased with increasing salinity level (Fig. 1h). Atrak showed significantly higher HI values than Tajan and Rasoul. Non-significant differences were observed for HI between Atrak and Kouhdasht at LS. At MS and HS, differences in HI became more pronounced: Kouhdasht showed significantly higher HI compared to the other genotypes, whereas, Atrak showed significantly higher HI than Rasoul and Tajan.

3.9 Leaf Na^+ Concentration

Leaf Na^+ concentration of all wheat genotypes increased significantly with increasing salinity levels as compared to the control treatment (Fig. 2a). At LS, Tajan maintained significantly higher Na^+ concentration than the other wheat genotypes, with the exception of Rasoul. Kouhdasht significantly maintained lowest Na^+ concentrations compared to the other genotypes under all salinity treatments. At MS and HS, genotypes were ordered in terms of leaf Na^+ concentration as: Tajan>

Rasoul > Atrak > Kouhdasht.

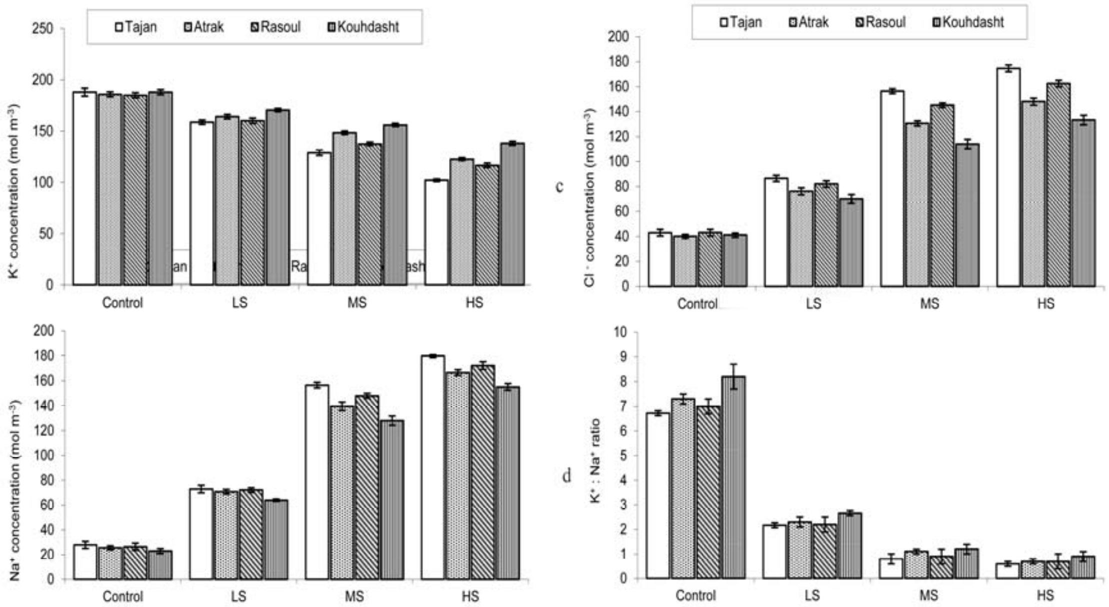

Fig. 2. Effects of different salinity levels on a) leaf K^+ concentration (mol m^{-3}); b) leaf Na^+ (mol m^{-3}); c) leaf Cl^- concentration (mol m^{-3}); and d) leaf K^+: Na^+ ratio. LS, MS and HS denote relatively low, moderate and high salinity level respectively; error bars indicate standard deviation

3.10 Leaf K^+ Concentration

Leaf K^+ concentration of all wheat genotypes significantly decreased with increasing salinity levels as compared to control treatment (Fig. 2b). Under all salinity levels, genotypes were ordered in terms of leaf K^+ concentration as: Kouhdasht > Atrak > Rasoul > Tajan, with all values being significantly different.

3.11 Leaf Cl^- Concentration

Chloride concentration in all wheat genotype leaves significantly increased with increasing salinity levels as compared to the control treatment (Fig. 2c). Under all salinity levels, genotypes were ordered in terms of leaf Cl^- concentration as: Tajan > Rasoul > Atrak > Kouhdasht, with all values being significantly different.

3.12 Leaf K^+: Na^+ Ratio

Leaf K^+: Na^+ ratio of all wheat genotypes decreased significantly with increasing salinity level as compared to control treatment (Fig. 2d). At LS, Kouhdasht showed significantly higher K^+: Na^+ ratio than the other genotypes. Non-significant differences were observed for the other three wheat genotypes. At MS and HS, Kouhdasht showed a significantly higher K^+: Na^+ ratio compared to the other genotypes, except for Atrak. Non-significant differences were observed in K^+: Na^+ ratio of Atrak and Rasoul, and also in K^+: Na^+ ratio of Rasoul and Tajan at the latter two salinity levels.

4. Discussion and Conclusion

Improving grain yield is an important target in wheat plant breeding. Therefore, the evaluation of final grain yield and growth parameters determining grain yield is a critical aspect of breeding programs. Final yields of wheat are determined by the number of spikes per plant and yield components such as spikelet numbers, grain number and grain weight (El-Hendawy *et al*., 2005). Grain yield and TGW of the four wheat genotypes tested here significantly decreased with increasing salinity levels. Kouhdasht and Tajan, respectively, showed the highest and the lowest grain yield and TGW values compared to the other wheat genotypes. For example, grain yield and TGW per plant at HS treatment were reduced by an average 39.7 and 29.8% (respectively, for grain yield and TGW) for Kouhdasht cultivar, whereas they were reduced by an average 62.2 and 46.9% for Tajan. Similarly, El-Hendawy *et al*. (2005) concluded that at final harvest, grain yield per plant at 150 mM NaCl (17 dS m^{-1}) was reduced by an average 22% for the most tolerant genotypes, whereas it was reduced by an average 61% for the least tolerant genotypes. Table 3 shows that spike length and spikelet number per spike have also a positive and highly significant correlation with grain yield under moderate and high salinity treatments. However, non-significant correlations were observed under low salinity treatment. TGW has a positive, and very strong and significant correlation with grain yield under moderate and high salinity, and a positive and strongly significant correlation under low salinity. Maas and Grieve (1990) observed reduction of spikelet and kernel number per spike under the influence of root zone salinity. Grieve *et al*. (1992) found a reduction in tillering capacity, spike length, number of spikelets and kernels per spike of moderately salt-stressed wheat. In the present study, values of parameters mentioned above, i.e. tiller number and leaf number, decreased with increasing salinity. Tiller numbers per plant of the salt-sensitive genotype (Tajan) showed a higher reduction (by about 37%) than tolerant genotype (Kouhdasht) (i.e. by about 19%). This may indicate that tiller number under salinity can be used as a simple and non-destructive measurement to evaluate salinity stress tolerance of wheat genotypes in breeding programs (El-Hendawy *et al*., 2005). Munns (1993) indicated that salt in plants reduces growth by causing premature senescence of old leaves and hence reduced supply of assimilates to growing regions. Significant decrease in spike length, spike number and spikelets number per spike of all wheat cultivars was observed with increasing salinity levels. Table 3 shows that spike length and spikelet number per spike have a positive and highly significant correlation with grain yield. Leaf Na^+ and Cl^- concentrations were increased by salinity, whereas the opposite was observed for leaf K^+ concentration and accordingly, the K^+: Na^+ ratio. K^+ had a positive and highly significant correlation with grain yield. Leaf Na^+ concentration of Kouhdasht under all salinity levels was significantly lower than that observed in other genotypes (Fig. 2a). Moreover, Kouhdasht accumulated highest K^+ concentration and had higher K^+: Na^+ ratio than that of other wheat genotypes. By contrast, Tajan maintained significantly higher leaf Na^+ concentration than the other genotypes (except Rasoul) under different salinity levels. In contrast, there is a highly significant positive correlation between grain yield and K^+ concentrations as well as with K^+: Na^+ ratio (Table 3).

Within a species, or even within a genus, leaf Na^+ concentrations can be used as an indicator of relative ability to 'exclude' Na^+. In addition, genotype tolerance to high Na^+ concentrations in leaves may differ, assumedly due to differences in compartmentation efficiency in leaf vacuoles; this trait has been characterized as 'tissue tolerance' (Munns, 2005; Flowers, 2004). The ability to maintain low Na^+ and high K^+ concentrations in leaves (Dvorak *et al*., 1994) and K^+: Na^+ discrimination can be found amongst wheat genotypes, wheat progenitors, and wild relatives (Chhipa and Lal, 1995; Gorham, 1993), although the relationship does not hold across all genotypes (Ashraf and McNeilly, 1988; El-Hendawy *et al*., 2005). Kouhdasht and Atrak either restricted the Na^+ uptake or excluded Na^+ from leaves, whereas Tajan and Rasoul were not able to exclude Na^+ from their leaves. Higher leaf Na^+ concentrations in Tajan and Rasoul might have inhibited K^+ uptake, and therefore, these genotypes maintained a low concentration of K^+ and consequently a low K^+: Na^+ ratio in their leaves. By contrast, Kouhdasht showed a restricted uptake of Na^+ and Cl^-, and a better maintenance of the proper K^+: Na^+ ratio. As Kouhdasht and Atrak were identified as the most salt-tolerant genotypes, they can be utilized through selection and breeding programs for further improvement in salt tolerance of Iranian wheat genotypes. Furthermore, as Atrak and Kouhdasht are also drought-tolerant (Kalateh *et al*., 2001), they may possibly be considered as drought/saline-tolerant genotypes in Iran.

Table. 3. Relationship between grain yield and yield components and leaf ion concentrations (Pearson correlation)

	GY	TGW	NTP	NSP	NSS	SL	SW	HI	Na^+	Cl^-	K^+
TGW	0.90**										
NTP	0.85**	0.80**									
NSP	0.81**	0.75**	O.79**								
NSS	-0.72**	-0.70**	-0.76**	0.64**							
SL (cm)	-0.65**	-0.55**	-0.64**	0.54**	0.75**						
SW (g/plant)	-0.57**	-0.68**	-0.72**	0.54**	0.68**	0.77**					
HI (%)	0.86**	0.83**	0.84**	0.84**	0.65**	-0.71**	0.68**				
Na^+	-0.79**	-0.75**	-0.78**	-0.74**	-0.56**	-0.65**	-0.55**	-0.78**			
Cl^-	-0.45**	-0.56**	-0.65**	-0.59**	-0.67**	-0.69**	0.61**	-0.78**	0.79**		
K^+	0.80**	0.78**	0.78**	0.74**	0.69**	-0.74**	0.76**	0.82**	-0.77**	-0.80**	
K^+:Na^+ratio	0.86**	0.81**	0.76**	0.78**	0.65**	-0.63**	0.56**	0.83**	-0.73**	-0.62**	0.83**

** Highly significant at P = 0.01 probability

GY, TGW, NTP, NSS, NSP, SL, SW, HI, Na^+, Cl^- and K^+ are respectively grain yield, 1000 grain weight, number of tillers per plant, number of spikelets per spike, number of spikes per plant, spike length, straw weight, harvest index, leaf Na^+ concentration, leaf Cl^- concentration and leaf K^+ concentration, respectively.

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