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Investigation of the Salt Tolerance of Wheat Genotypes: Changes in Antioxidants, Total Protein, K^+/Na^+ Ions and Grain Yield

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Authors' contributions

This work was carried out in collaboration between both authors. Author SK conducted the experimental works and performed the statistical analysis. Author BH designed the study, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Salt stress causes huge losses of agricultural productivity worldwide, negatively affects soil properties and limits plants growth. In the present study, response of 11 wheat (*Triticum aestivum*) landrace varieties, 2 commercial cultivars and 2 promising lines to three levels of salinity (EC= 7, 14 and 21 dS m^{-1}) was assessed based on variations in grain yield, antioxidants, and Na^+ and K^+ ions. Pots were daily weighed and irrigation with saline solution (1:1 ratio of NaCl and $CaCl_2$ salts) was performed based on field capacity (FC) 50 days after sowing at the four-leaf stage of growth. Results of linear regression showed that K^+/Na^+ ratio had strong direct relation (R^2=0.98) in root and leaf. Correlation between grain yield in control and salinized conditions was supported by positive regression coefficient (b=0.853) in regression equation (R^2=0.65). This correlation showed that superior genotypes in control condition produced higher grain yield under salinized conditions. Enzymatic antioxidants (superoxide dismutase, SOD and peroxides, POD) and total protein content were increased as the level of salinity increased from EC= 7 to EC=21 dS m^{-1}. K^+/Na^+ ratio in the leaf and grain yield were reduced as the level of salinity increased. Overall, results showed that

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great variations was existed between genotypes for three types of traits and selections can be made using a weighted index defined based on changes in antioxidants, protein, ions and grain yield.

Keywords: Triticum aestivum; salinity; SOD; POD; K^+/Na^+.

1. INTRODUCTION

Salt stress causes huge losses of agricultural productivity worldwide. Salinity negatively affects soil properties and limits plants growth [1]. In Iran, about 34 million ha which is equivalent to 20% of arable lands are affected by salinity [2]. Apart from natural soil salinity it is also evoked by agronomic practices, such as improper irrigation and fertilization. In most cultivation area of Iran, low annual precipitation necessitates irrigation with water which sometimes could not be completely desalted. However, in most cases soil salinity is an effect of salt accumulation over long cultivation periods and deforestation [3]. The deleterious effects of salt stress can be alleviated by either soil reclamation or production and cultivation of salt-tolerant crops [4]. Due to expensive process of soil reclamations, researchers prefer investigation for salt tolerant plants as more practical solution. Although significant genotypic differences have been found with respect to between and within plant species [5,6], selection of appropriate criteria and tools is important for improvement of salt tolerance in crop plants. Screening for the salt tolerance based on grain yield is a final stage of both plant breeders and agronomist which is costly and time consuming [6]. However, investigation of salt tolerance at the early stages of crop growth may lead to a considerable saving in time and a reduction in overall cost. This necessitates association of salt tolerance at the early growth and other growth stages. Activities of antioxidants such as superoxide dismutase (SOD) and peroxidase (POD) during the vegetative and developmental stages of plants increase under abiotic stresses in wheat. Enzymatic antioxidants make a defence line against free radicals and detoxify reactive oxygen species (ROS) induced by salinity stress [7,8]. Association of increased antioxidants and higher grain yield has been reported in previous works [8,9,10,11] which shows they can be used as efficient criteria for screening salt-tolerant crop plants.

Salt stress creates both ionic and osmotic stresses on plants. Na^+-specific damage is associated with Na^+ in leaf tissues and results in necrosis of older leaves [12]. Also, Na^+ interferes with transporters in root plasma membrane and root growth. Among ions, K^+ activates more than 50 enzymes that take part in protein synthesis and other metabolisms [13]. High K^+/Na^+ ratio is associated with higher grain yield and salt tolerance [7]. There are a number of possible mechanisms by which a cereal can tolerate high levels of salinity. As in wheat, salt tolerance is associated with low rates of transport of Na^+ to shoot, with high selectivity for K^+ over Na^+ [14,15,16]. Bread wheat is affected by a low rate of Na^+ accumulation and an enhanced K^+ /Na^+ discrimination. In a study in Pakistan, the tolerant genotypes expressed the same trend for K^+ /Na^+ ratios and salt-tolerant genotypes such as Lu-26s and KTDH comparatively accumulated higher K^+ than sensitive ones [17]. Such studies show that existence of genetic variation among germplasms is important for selection and breeding for salt tolerance characters. Accumulation of ions is an efficient criterion for screening salt tolerant wheat genotypes under salinity stress conditions. Therefore, the aims of this study were to (1) investigate variations in grain yield, antioxidants and physiological traits as affected by different salinity levels, (2) assay response of wheat genotypes to different levels of salinity stress and (3) identify more tolerant wheat genotypes for possible use in further breeding programs of salt tolerance.

2. MATERIALS AND METHODS

2.1 Plant Material and Experimental Design

Fifteen wheat genotypes comprised of 11 landrace varieties, 2 commercial cultivars and 2 promising lines were used for investigation of salinity tolerance within a greenhouse in the College of Agriculture, Shiraz University, Iran (Table 1).

Landrace varieties previously showed drought tolerance in the field experiments conducted by Heidari et al. [9] and Ghaedrahimi et al. [10]. Experimental design was factorial based on completely randomized design (CRD) with 3 replications. Saline solutions with EC=7, 14 and

21 dS m^{-1} were prepared by combining $CaCl_2$ and NaCl salts with 1:1 ratio. A normal water irrigation regime was used as control. The soil was sandy clay sit with electrical conductivity (EC) of 0.254 dS m^{-1} and pH 7.8. Available K^+ and Na^+ of the soil were respectively 68 and 26.5 mg ml^{-1}. At the beginning, ten seeds were sown and later at the two-leaf stage two seedlings per pot were left. Salinity treatments were performed 50 days after sowing which was coincident with the four-leaf stage of growth. To perform salinity stress treatments, pots were daily weighed and irrigation with saline solution was conducted based on field capacity (FC). The effects of salinity on three types of traits comprised of grain yield, antioxidants and physiological features were assayed.

2.2 Assays for Antioxidant Variations

Seventy two hours after the last irrigation with saline solutions, samples of 0.5 g fresh leaves were selected for quantifying protein content and antioxidants including super oxide dismutase (SOD) and peroxidase (POD). SOD activity was quantified on the basis of Beauchamp and Fridovich [18] procedure. Amount of enzyme needed for the inhibition of photo reduction of nitro blue tetrazolium (NBT) by 50% was a basis for the determination of unit of SOD enzyme. Light absorbance for unit of enzyme was spectrophotometrically read at 560- nm wave length. A procedure proposed by Chance and Manly [19] was used for POD assay. A solution mixed of H_2O_2, potassium phosphate 50 mM (pH 7) and guaiacol 13 mM was used for spectrophotometrically read at 470- nm wave length. Total protein content was measured following a method proposed by Bradford [20].

2.3 Ion Measurement

Na^+ and K^+ ions were measured at the pre-heading stage of growth. Leaves in each pot were collected and oven-dried at 70˚C for 48 h and were milled to a fine powder. The samples were placed in a crucible and ashed by transferring to a furnace at 500°C for 2 h. An amount of 5 ml HCL (2N) was added to each crucible and mixed thoroughly. Then, boiling distilled water was added to the mixture and then filtered in a 50 ml volumetric flask. Concentrations (mg g^{-1} of dry matter, DM) of Na^+ and K^+ ions were measured using flame photometry according to Hamada [21] procedure. K^+/Na^+ ratio was calculated.

2.4 Statistical Analysis

The data collected from each pot for grain yield, antioxidants and ions were subjected to analysis of variance (ANOVA) for a factorial experiment based on completely randomized design in SAS 9.4 software. ANOVA for comparison of the means was also performed using statements defined in SAS 9.4 computer program. A linear regression analysis was performed to pursue the relationship between K^+/Na^+ ratio in leaf and root and between grain yield in control and salinized conditions.

3. RESULTS AND DISCUSSION

3.1 Variations in Antioxidants and Total Protein Content

Results of ANOVA indicated that the main effects of salinity and genotypes were significant for POD, SOD and protein content (data not shown). In genotypes irrigated with normal water, POD (U mg^{-1} fresh weight) varied between 7.845 and 12.556 (Table 1).

In EC= 7 dS m^{-1} and 14 dS m^{-1}, the range of POD was from 8.521 to 13.158 and from 8.897 to 12.957, respectively. Treating genotypes with saline solution of EC= 21 dS m^{-1} caused a variation of 10.05 (in Shiraz) to 13.559 (in Kc4633) for POD. Results of mean comparison indicated that POD activity in genotypes treated with normal water and salinity solution of EC=7 dS m^{-1} were not significantly different. Values in irrigation regime of EC=21 dS m^{-1} were meaningfully higher compared with other salinity levels. This shows that changes in POD as a defence line was more responsive in higher levels of salinity. The landrace variety Kc4633 accumulated relatively high POD under three levels of salinity and normal irrigation regime. Means for SOD activity (U mg^{-1} fresh weight) in genotypes under four levels of irrigation regimes are presented in Table 2.

SOD activity in three levels of salinity varied from 7.682 in EC=7 dS m^{-1} to 10.971 in EC=21 dS m^{-1}. In most of genotypes, SOD activity increased when the level of salinity was increased. Three landrace varieties comprised of Kc4557, Kc4633 and Kc4542 showed higher SOD activity in three levels of salt treatment. These genotypes showed higher SOD activity when treated with saline solution with EC=21 dS m^{-1} as compared with SOD activities in EC= 7

and 14 dS m^{-1} levels. In a study with two finger millet cultivars, SOD and CAT activities under saline solutions were increased by 0.2-1.5 and 0.2-0.7 fold as compared with plants of control conditions [8]. Results for variations in protein content (mg ml^{-1}) in response to salinity stress are shown in Table 3.

Protein content varied from 47.08 to 57.64 in control and from 47.5 to 68.89 in three levels of salinity. Genotypes accumulated higher proteins when treated with more severe salt stress. Genotypes that were irrigated with saline solution of EC= 21 dS m^{-1} had higher proteins than their counterparts treated with saline water with EC= 7 and 14 dS m^{-1}. Kc4633 and Kc4542 which showed high SOD activity under three levels of salinity also accumulated higher protein. Kc4557 was also among top 5 rankings for higher protein in three levels of salinity.

Table 1. Means for peroxidase (POD) activities (U mg^{-1} fresh weight) in wheat genotypes in three levels of salinity

Genotype	Control	Salinity stress		
		7 dSm^{-1}	14 dSm^{-1}	21 dSm^{-1}
Navid	8.321 d-f	11.228 a-f	8.897 b-f	11.328 a-f
Kc4557	10.602 a-f	9.474 a-f	10.226 a-f	11.504 a-f
Kc4495	11.454 a-f	9.474 a-f	10.226 a-f	11.429 a-f
Kc4633	11.103 a-f	10.15 a-f	11.128 a-f	13.559 a
Kc4604	8.571 d-f	11.404 a-f	9.474 a-f	11.078 a-f
Kc4537	9.173 b-f	9.699 a-f	12.957 a-c	10.752 a-f
Kc4542	12.556 a-d	11.805 a-f	12.155 a-f	12.531 a-e
Kc4862	9.048 b-f	11.679 a-f	10.075 a-f	11.003 a-f
Kc4543	7.845 f	11.404 a-f	10.075 a-f	11.704 a-f
Kc2165	9.173 b-f	13.158 ab	10.902 a-f	11.504 a-f
Kc3891	8.221 ef	8.521 d-f	10.226 a-f	10.376 a-f
L32	11.153 a-f	8.797 c-f	9.148 a-f	12.005 a-f
Kc4551	11.003 a-f	8.997 b-f	10.175 a-f	10.725 a-f
Shiraz	8.421 d-f	80872 b-f	9.398 a-f	10.05 a-f
L372	11.303 a-f	9.95 a-f	10.752 a-f	13.033 a-c

Means with different letters showed significant differences

Table 2. Means for superoxide dismutase (SOD) activities (U mg^{-1} fresh weight) in wheat genotypes in three levels of salinity

Genotype	Control	Salinity stress		
		7 dSm^{-1}	14 dSm^{-1}	21 dSm^{-1}
Navid	7.3951 m	7.6821 j-m	7.9029 h-m	9.117 d-l
Kc4557	7.7925 i-m	8.4989 e-m	9.2053 c-k	10.083 a-e
Kc4495	7.5497 k-m	7.8587 h-m	8.2561 g-m	8.8742 d-m
Kc4633	8.5872 e-m	8.7638 d-m	9.6689 a-g	10.9272 ab
Kc4604	7.4393 l-m	7.7925 i-m	8.1236 g-m	9.4923 a-h
Kc4537	8.8962 d-m	8.2561 g-m	8.8079 d-m	9.6026 a-g
Kc4542	8.1678 g-m	10.1325 a-e	10.7947 a-c	10.9713 a
Kc4862	9.2936 c-j	8.1236 g-m	8.3223 g-m	9.3377 b-j
Kc4543	8.6534 e-m	8.0321 g-m	8.7417 e-m	10.4194 a-d
Kc2165	8.8079 d-m	8.1457 g-m	8.4106 f-m	9.6226 a-g
Kc3891	7.4834 l-m	7.5717 k-m	8.8079 d-m	9.0066 d-m
L32	7.6821 j-m	8.9183 d-m	9.4702 a-h	10.00008 a-f
Kc4551	8.4989 e-m	7.9912 g-m	8.8079 d-m	9.3598 a-j
Shiraz	8.8742 d-m	8.1236 g-m	8.8742 d-m	10.00005 a-f
L372	8.0795 g-m	9.2715 c-j	8.8742 d-m	10.1766 a-e

Means with different letters showed significant differences

Table 3. Means for protein content (mg ml^{-1} fresh matter) in wheat genotypes in three levels of salinity

Genotype	Control	Salinity stress		
		7 dSm^{-1}	14 dSm^{-1}	21 dSm^{-1}
Navid	47.08 lm	47.92 j-m	49.31 h-m	57.50 c-k
Kc4557	49.17 i-m	54.17 d-m	57.50 c-k	62.64 a-e
Kc4495	47.50 j-m	48.89 i-m	51.53 f-m	55.42 d-l
Kc4633	55.69 d-l	55.28 d-l	60.00 a-g	68.33 ab
Kc4604	47.22 k-m	49.17 i-m	51.11 f-m	58.61 b-i
Kc4537	57.22 c-l	51.67 f-m	55.00 d-l	60.42 a-g
Kc4542	55.83 d-l	64.31 a-d	67.36 a-c	68.89 a
Kc4862	57.22 c-l	53.33 e-m	52.92 e-m	59.17 a-i
Kc4543	55.28 d-l	50.83 g-m	55.69 d-l	56.53 d-l
Kc2165	59.03 a-i	51.11 f-m	53.06 e-m	61.25 a-f
Kc3891	44.07 m	47.50 j-m	58.75 b-i	57.22 c-l
L32	57.64 c-j	55.83 d-l	59.72 a-g	59.17 a-i
Kc4551	47.64 j-m	50.42 g-m	55.69 d-l	59.58 a-h
Shiraz	54.86 d-l	52.08 f-m	55.42 d-l	63.19 a-e
L372	51.25 f-m	58.75 b-i	55.83 d-l	63.75 a-d

Means with different letters showed significant differences

3.2 K^+/Na^+ Ratio in Root and Leaf

Means for K^+/Na^+ ratio in root and leaf of genotypes under four levels of irrigation regimes are available in Tables 4 and 5. Except for Shiraz, Kc3891, Kc2165 and Kc4495, K^+/Na^+ ratio in the root was higher in genotypes irrigated with salinity level of EC=21 dS m^{-1} in comparison with this ratio in plants that were irrigated with EC=7 dS m^{-1}. Plants shut down root hydraulic permeability (*Lpr*) even upon moderate salinity stress conditions to get ready for more severe stress in advance because such a sequence occurs in nature (that is, moderate stress gradually succeeds to more severe one [1]. Na^+ inhibits the uptake of other nutrients such as K^+ directly by interfering with transporters in the root plasma membrane and prevents root growth by the osmotic effects on Na^+ on soil structure. As a consequence, uptake of water, growth-limiting nutrients and the frequency and growth of microorganisms (i.e. mycorrhizal fungi) can be prevented [12].

Table 4. Means for K^+/Na^+ ratio in roots of wheat genotypes in three levels of salinity

Genotype	Control	Salinity stress		
		7 dSm^{-1}	14 dSm^{-1}	21 dSm^{-1}
Navid	1.35 g-j	0.90 j-q	1.08 h-n	1.20 h-k
Kc4557	1.37 g-j	0.15 u-w	0.12 vw	0.69 l-s
Kc4495	0.65 m-u	1.91 d-f	2.21 b-d	0.72 k-r
Kc4633	1.59 f-h	0.33 r-w	0.15 u-w	0.67 m-t
Kc4604	1.72 e-g	0.58 n-w	0.25 r-w	0.57 n-w
Kc4537	1.38 g-j	0.54 o-w	0.38 q-w	0.58 n-w
Kc4542	1.22 h-k	0.92 i-p	0.34 r-w	0.52 o-w
Kc4862	2.08 c-e	1.48 f-h	0.46 o-w	0.65 m-v
Kc4543	2.32 b-d	0.15 u-w	0.13 u-w	1.14 h-m
Kc2165	0.61 n-w	2.62 ab	2.10 c-e	0.65 m-v
Kc3891	0.95 i-o	1.20 h-k	0.60 n-w	0.55 o-w
L32	1.43 g-i	0.24 r-w	0.33 r-w	0.41 p-w
Kc4551	0.61 n-w	1.18 h-l	0.10 w	0.50 o-w
Shiraz	2.87 a	2.42 bc	0.72 k-r	0.63 n-w
L372	1.56 f-h	0.16 s-w	0.56 n-w	0.36 r-w

Means with different letters showed significant differences

Table 5. Means for K^+/Na^+ ratio in leaves of wheat genotypes in three levels of salinity

Genotype	Control	Salinity stress		
		7 dSm^{-1}	14 dSm^{-1}	21 dSm^{-1}
Navid	14.51 a	8.00 g-l	11.29 b	6.86 j-n
Kc4557	10.44 b-d	7.09 i-n	5.89 n-q	5.35 o-s
Kc4495	8.83 e-g	6.78 k-n	5.05 p-s	3.59 u-y
Kc4633	6.51 m-o	8.18 f-k	3.83 t-x	2.55 x-z
Kc4604	9.49 d-f	5.67 n-r	4.67 q-v	2.69 w-z
Kc4537	8.44 f-i	4.83 q-u	2.95 w-y	2.01 yz
Kc4542	3.28 v-y	2.39 x-z	2.08 yz	1.54 z
Kc4862	8.21 f-j	7.32 h-m	6.27 m-p	3.91 t-x
Kc4543	13.43 a	8.62 e-h	5.84 n-q	4.35 r-v
Kc2165	13.65 a	7.61 g-m	8.10 g-l	5.76 n-q
Kc3891	10.89 bc	9.82 c-e	6.54 m-o	3.31 v-y
L32	4.02 s-w	2.89 w-z	2.49 x-z	1.56 z
Kc4551	7.45 g-m	7.04 i-n	6.70 l-o	5.05 p-s
Shiraz	1.61 b	10.66 b-d	8.24 f-j	6.31 m-p
L372	3.77 t-y	2.70 w-z	1.63 z	1.27 z

Means with different letters showed significant differences

In the present study, K^+/Na^+ ratio was reduced in the leaf of genotypes as the level of salinity (EC) was increased. This shows that accumulation of K^+ ion in leaves decreased when plants treated with higher levels of salinity. The decrease in K^+ is due to the presence of excessive Na^+ in saline solutions and that external Na^+ has an antagonistic effect on K^+ uptake [22]. K^+/Na^+ ratio in leaf changed from 1.61 Shiraz to 14.51 in Navid when genotypes irrigated with normal water.

Among landrace varieties, Kc2165 and Kc4543 had the highest K^+/Na^+ ratio in normal water irrigation regime. Shiraz and Navid showed relatively high ion ratio in salinity levels of EC= 7, 14 and 21 dS m^{-1}. Among landraces, Kc2165 and Kc4543 had relatively high ion ratio under three levels of salinity. Ion accumulations in the cytosol (mainly K^+) and in the vacuole (Na^+, especially in salt tolerant cultivars/species) are important for the osmotic adjustment of plant cells [23]. Plants differ genetically in response to salinity stress. Regulation of K^+ uptake and prevention of Na^+ from entrance and efflux of Na^+ from cells are efficient strategies that plants use for salt tolerance and maintenance of K^+/Na^+ ratio at desirable level in the cytosole [24]. Khan et al. [17] evaluated K^+/Na^+ ratio in wheat treated with 12 dS m^{-1} salinity solution and results indicated that this ratio was higher in genotypes with higher grain yield. Also, they indicated that high K^+/Na^+ was correlated with high proline and chlorophyll contents.

3.3 Relationship between K^+/Na^+ Ratio in Root and Leaf

Results of linear regression analysis for relationship between K^+/Na^+ ratio in root and leaf is shown in Fig. 1. The linear regression model was as below:

$$Y=10.41+1.68\ X$$

where, Y and X refer to K^+/Na^+ ratios in leaf and root, respectively. The coefficient of determination of this equation was 98% which shows the strong association of the ratio in root and leaf of wheat genotypes. Regression model shows that K^+/Na^+ ratio in root has direct relation with the ratio in leaf and that leaves showed higher magnitudes for K^+/Na^+ when the ratio of ions were increased in roots. It can be concluded that leaves accumulated lower K^+ when roots encountered with higher concentrations of Na^+. This may be due to competition between the exchange of K^+ and Na^+ ions between root and leaf under high concentration of salt in the soil. Keeping cytosolic Na^+ levels low at the cellular level and shoot Na^+ concentrations low at the whole plant level along with acquisition and maintenance of K^+ were found to have a considerable impact on plant salt tolerance [25,26,27,28,29]. Maintenance of high cytosolic K^+/Na^+ ratios especially in shoots have been strongly suggested to be crucial for salt tolerance of plants.

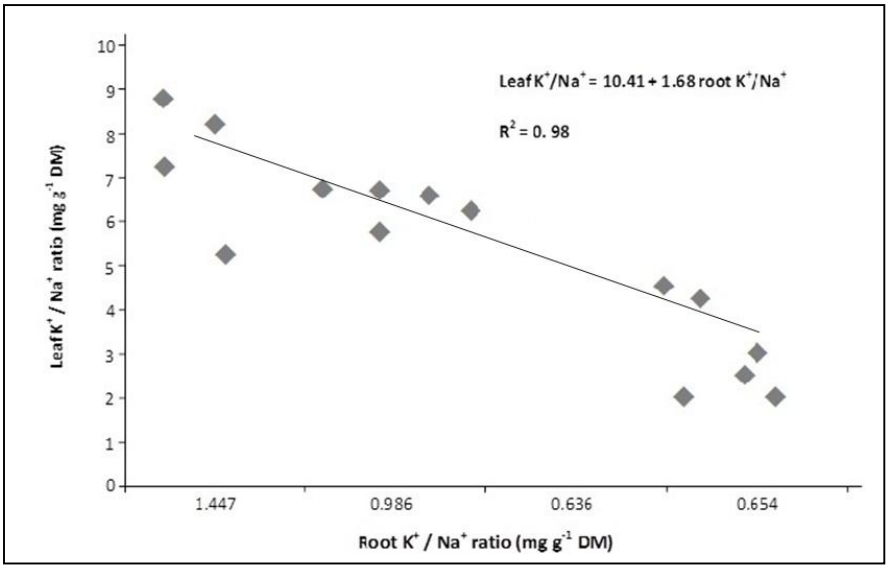

Fig. 1. Relationship between K^+ / Na^+ ratio (mg g^{-1} dry matter, DM) in leaf and root of wheat genotypes treated with saline solutions

3.4 Grain Yield Variation as Affected by Salinity Stress

Grain yield significantly decreased as the level of salinity was increased (Table 6). Genotypes irrigated with normal water had the highest grain yield but the lowest grain yield was found in the plants irrigated with solutions of EC=21 dS m^{-1}. Range of grain yield was from 1.78 to 5.14 g under normal irrigation regime. In the salinity level of 7 dS m^{-1}, Kc4542 (5.36 g), L32 (5.28 g), Kc4862 (5.27 g), Kc4551 (5.26 g) and L372 (5.02) had the highest grain yield. Kc4542 (5.1 g) and L32 (4.03 g) and Kc4862 (3.27) had higher grain yield compared with other genotypes under 14 dSm^{-1} salinity level. Some studies emphasized that two possible reasons exist for reduction in growth in NaCl treatments with the concentration of less than 100 mM (10 dS m^{-1}). First, plants shut down root hydraulic permeability (*Lpr*) even upon moderate salinity stress conditions to get ready for more severe stress in advance. Second, *Lpr* reductions could be a sign of conversion of the growth status of plant cells from the rapid growth mode with high water absorption to the protect/tolerant one with less water uptake as a strategy for the survival under salinity stress [1,30].

Table 6. Means for grain yield (g $plant^{-1}$) of wheat genotypes in three levels of salinity

Genotype	Control	Salinity stress		
		7 dSm^{-1}	14 dSm^{-1}	21 dSm^{-1}
Navid	2.78 h-l	1.75 l-p	1.44 o-q	0.40 q
Kc4557	3.67 e-j	1.60 n-p	1.20 pq	0.77 pq
Kc4495	4.86 a-d	4.72 a-e	3.44 f-k	2.55 j-n
Kc4633	3.46 f-k	1.35 o-q	1.09 pq	0.69 pq
Kc4604	5.06 ab	4.94 a-c	3.90 c-h	3.23 f-k
Kc4537	1.78 l-p	1.55 n-p	1.64 m-p	0.71 pq
Kc4542	5.14 ab	5.36 a	5.10 ab	0.97 pq
Kc4862	4.73 a-e	5.27 a	3.78 d-i	3.28 a-f
Kc4543	5.03 ab	3.25 f-k	2.97 g-k	0.69 pq
Kc2165	3.45 f-k	2.93 g-k	3.27 f-k	1.16 pq
Kc3891	4.89 a-c	4.82 a-d	2.65 j-n	2.63 j-n
L32	5.11 ab	5.28 a	4.03 b-g	3.25 f-k
Kc4551	5.14 ab	5.26 a	2.63 j-n	0.79 pq
Shiraz	2.71 i-m	2.94 g-k	0.89 pq	0.76 pq
L372	5.07 ab	5.02 ab	2.33 k-o	1.63 m-p

Means with different letters showed significant differences

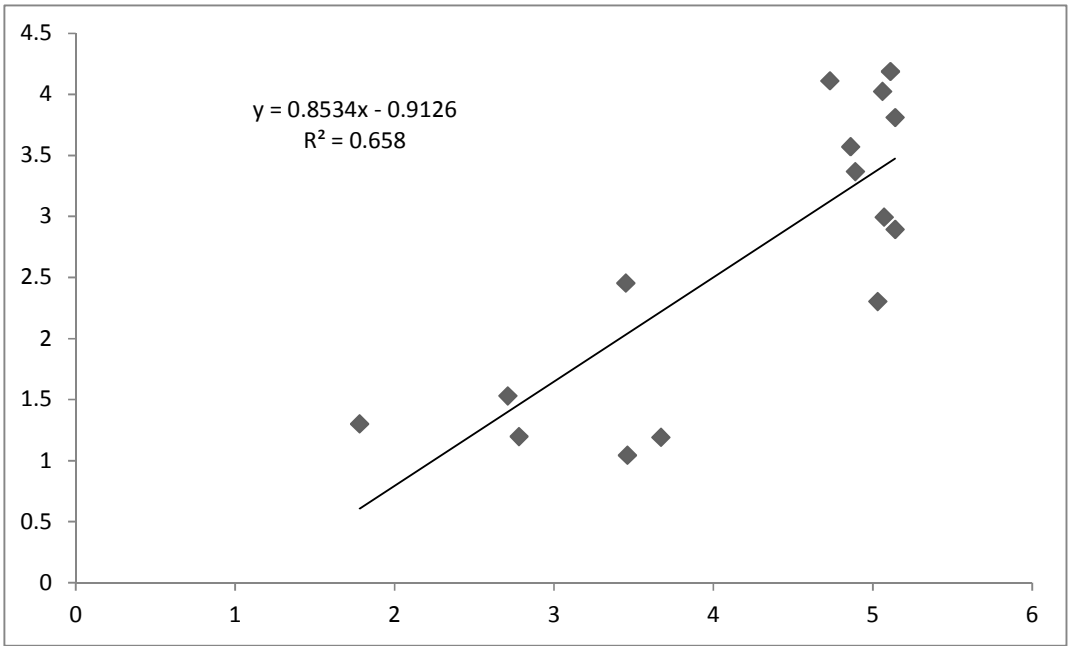

Fig. 2. Correlation between wheat grain yield (g plant^{-1}) in control (horizontal axis) and salinized conditions (vertical axis). X and Y in regression equation refer to grain yield in control and salinized conditions

3.5 Correlation of Grain Yield in Control and Saline Conditions

A simple linear regression model was found for the relationship between grain yield in control and salinized conditions. Following equation indicated positive correlation between grain yield of genotypes in control treatment and grand mean of three salinity levels.

Grain yield (saline conditions) = 10.41+1.68 (grain yield in control conditions)

This relation is shown in Fig. 2 above. Fig. 2 showed that the coefficient of determination for above equation was relatively high (R^2=658) and that differences in grain yield under saline conditions simply reflects differences in plant vigour. Breeding for more vigorous plants has been argued to be agronomically the most effective strategy for production of higher grain yield under saline conditions [12,31]. Results of a study [31] indicated that grain yield in control and salinized conditions had close correlations. Such correlation appears to be particularly string in the graminaceous species [12].

4. CONCLUSSION

Morphological barriers at cellular and whole plant levels are crucial to develop high-yielding salt tolerant cultivars. In the present study, response of 15 wheat genotypes to three levels of salinity was investigated in greenhouse. Results indicated that antioxidant activity increased as the level of salinity stress was increased but grain yield decreased. Results also indicated that genotypes had great variations under salinity stress condition on the basis of agronomic and biochemical data that shows existence of genetic variation for salinity tolerance. The coefficient of determination of linear regression model indicated strong association of the ions ratio in root and leaf in wheat genotypes. In the present study, some of genotypes had higher grain yield and also K^+/Na^+ ratio and they can be selected as candidates to be involved in breeding programs targeting salinity tolerance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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