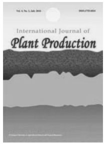

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Screening Egyptian Wheat Genotypes for Salt Tolerance at Early Growth Stages

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Abstract

Parameters that show a significant genotypic variation at early growth stages and are associated with salt tolerance at later stages may be used as rapid and economic screening criteria in breeding programs. The objective of this study was to test growth parameters at early growth stages for evaluating the salt tolerance of wheat genotypes. Ten wheat genotypes that differ from their salt tolerance were grown in soil and exposed to four salinity concentrations (0, 40, 80 and 160 mM NaCl). Germination percentage was recorded daily up to 8 days. Seedling growth parameters (i.e. shoot height, dry weight of shoots and roots and root/shoot ratio) were determined at day 14 after sowing. The results showed that salinity did not affect final germination percentage, while seeds subjected to 80 and 160 mM NaCl retarded germination by 1 and 2 days, respectively, as compared with 0 mM NaCl treatment. Salinity affected shoot growth more severely than root growth of seedlings. Importantly, height and dry weight of shoot ranked genotypes in the same order as their salt-tolerance rankings in terms of grain yield, whereas root dry weight did not. Therefore, we conclude that the measurements of shoot growth may be effective criteria for screening wheat genotypes for salt tolerance at early growth stages.

Keywords: Germination index; Grain yield; Ranking; Root dry weight; Salinity; Screening criteria; Shoot dry weight.

Introduction

Over 6% of the world's total land area and 20% of the irrigated land are salt-affected (FAO, 2008). Most importantly, between 35% and 50% of the world's population in about 80 countries are in semiarid areas where salinization is a major problem. Egypt presents a typical example of the problems faced by countries in such areas. Obviously, improvement of the salt tolerance of genotypes has been proposed as the most effective way to reducing the deleterious effects of salinity on crop production (Pervaiz et al., 2002) because this strategy is still much less expensive for poor farmers in developing countries and is more feasible to apply on a large scale than using other management practices (e.g. leaching salt from the soil surface etc., Qureshi and Barrett-Lennard, 1998). One of the critical issues restricting breeding efforts to enhance the salt tolerance of genotypes is the lack of effective evaluation methods and selection criteria for screening the salt-tolerance among genotypes, especially at the early stages (Zeng et al., 2002; Koyro and Huchzermeyer, 2004). Therefore, it is very important to develop an effective evaluation approach for screening the salt-tolerance among genotypes, which should be quick, economic and reliable.

Because screening the salt tolerance of genotypes based on grain yield, which is considered as a final target of both the plant breeder and agronomist, is costly and time consuming, evaluating the salt tolerance at early vegetative growth stages may lead to a considerable saving in time and a reduction in overall cost. However, this is particularly true if the degree of salt tolerance of genotypes at the early growth stage is associated with that developed during the other growth stages (Hu et al., 2005). A number of researches have suggested that evaluating salt tolerance of genotypes at one growth stage could be effective if the evaluation was done at the sensitive growth stage of crops (Allen et al., 1985; Ashraf et al., 1993; Ferdose et al., 2009, Mohammadi-Nejad et al., 2010). For example, sugar beet is most sensitive to salt stress at the germination stage (Läuchi and Epstein, 1990), and selection for salt tolerance at this stage is, therefore, effective in enhancing tolerance throughout its later stage (Wahid et al., 1997). Previous studies about alfalfa crop showed that selection and breeding are effective in improving salt tolerance at the germination stage (Allen et al., 1985) and at the seedling stage (Al-Khatib et al., 1993) due to the existence of genetic variation at both stages. Some investigators found that salt tolerance among melon cultivars during early seedling growth correlated well with the salt tolerance based on fruit yield at the end of the season (Nerson and Paris, 1984). In wheat, the seedling or early vegetative growth stage is known to be more sensitive to salt stress compared with later growth stages (Francois et al., 1994; Bhutta and Hanif, 2010; Khayatnezhad and Gholamin, 2010). Therefore, evaluating salt tolerance at early vegetative growth stages will be possible to screen salt tolerance of wheat genotypes, and simple and quick for evaluating salt tolerance of genotypes with a minimum investment of cost and time.

It is well known that although the final yield of wheat is directly determined after anthesis, the grain yield can be described in terms of components that are determined sequentially in the course of phenological development (Grieve et al., 2001). Numbers of plant per square meter and tillers per plant that are main components of the final grain yield of wheat are initiated at germination and early vegetative growth stages, respectively (Naseer et al., 2001). Therefore, any impairment in seed germination or seedling development due to salt stress can cause significant depressions in yield formation. Furthermore, genotypes, which exhibited salt tolerance at early stage, but did not at late stage, can be exploited in breeding programs (Sabir and Ashraf, 2008).

The objectives of this study were to determine the impact of salt stress on germination and seedling growth of different wheat genotypes, to investigate the possibility of selecting salt tolerance of wheat genotypes at germination and seedling stages, and to find out whether parameters measured at both stages are correlated with salt tolerance at maturity stage.

Materials and Methods

Plant materials

Ten genotypes of spring wheat (*Triticum aestivum* L.) were used in this study. Eight genotypes (Sakha 8, Sakha 93, Sakha 61, Sakha 69, Giza 168, Sids 1, Sahel 1 and Gemmeza 7) were obtained from the Field Crop Research Institute at Giza of Egypt. Additionally, Thassos and Triso were obtained from Germany. These genotypes had previously been evaluated for their salt tolerance concentrations at vegetative, reproductive and maturity stages using multiple agronomic parameters (El-Hendawy et al., 2005a). According to those studies, Sakha 8 and Sakha 93 were ranked as the most tolerant to salinity. A change in salt tolerance with growth stages was observed for Sids 1 and Gemmeza 7. Sakha 69 was ranked as moderately tolerant. The remaining genotypes showed the lowest tolerance to salinity at all growth stages.

Growth conditions

In this study, the wheat genotypes were evaluated for salt tolerance during germination and seedling stages at 0, 40, 80 and 160 mM NaCl concentrations with electrical conductivity values in the soil solution of 0.2, 6.8, 11.2 and 17.1 dS m^{-1}, respectively. Loamy soil collected from the soil surface (0-15 cm) was air-dried, ground, sieved through a 5-mm mesh screen and thoroughly mixed with tap water or NaCl solutions for control or salinity treatments, respectively, to reach a final soil water content of 25% on a dry soil basis. Thereafter, the soil was filled into the pots (12 cm in diameter and 10.5 cm in height). Fifteen seeds of each genotype were sown in each pot at a depth of 2.5 cm. During the experimental period, the pots were weighed daily and the water loss was replaced by adding tap water as needed. A randomized complete block design with a split plot arrangement of treatments and four replications was used with NaCl concentrations as main plots and genotypes randomized within each main plot. The experiment was conducted in a growth chamber under dark conditions for the first three days and at day/night temperature of 23/18 °C, followed by a 14-h light period of photon flux density 325 mmol m^{-2} s^{-1} and relative humidity of 80% for 11 days. Temperature and relative humidity were measured and controlled automatically in the computerized growth chamber.

Measurements

Counts of germinating seeds were recorded each 12 h for 8 days. Seeds were considered germinated when the emergent radicle reached 2 mm in length. Speed of germination was evaluated by the germination index (GI). The GI was calculated as described in the Association of Official Seed Analysis (AOSA, 2004) with the following formula:

$$GI = \frac{No.\ of\ germinated\ seed}{Days\ of\ first\ acount} + ... + \frac{No.\ of\ germinated\ seed}{Days\ of\ final\ acount}$$

The germinated seeds were recorded at 4th day after sowing. Measurements at the seedling stage were conducted at 14 days after sowing. Ten plants from each pot were harvested and the distance from crown to leaf tip was measured as shoot height. The roots were carefully and thoroughly extracted from the soil by gently rinsing with tap water. Thereafter, the roots were placed above blotter paper for 10 minutes. The samples of shoots and roots were dried at 70 °C for 48 h to determine the dry weight of shoots (DW_{shoot}) and roots (DW_{root}).

Ranking of genotypes for salt tolerance

Following Zeng et al. (2002) and El-Hendawy et al. (2005a), all the data were converted to salt tolerance indices before cluster analysis to allow comparisons among genotypes for salt tolerance by using different salinity concentrations. A salt tolerance index was defined as the observation at salinity divided by the average of the controls. Cluster group ranking numbers can be assigned to cluster groups based on cluster means, and were used to score genotypes. Cluster analysis followed the methods described by Jollife et al. (1989). Cluster group rankings were obtained based on Single-Link cluster analysis of the means of the salt tolerance indices for all measurements at seedling stage. All procedures are described fully in the JMP User's Guide (SAS Institute, 2000). A sum was obtained by adding the number of cluster group rankings at each salt concentration in each genotype. The genotypes were finally ranked based on the sums, such that those with the smallest and largest sums were ranked respectively as the most and least tolerant genotypes in terms of relative salt tolerance.

Statistical analysis

All measurements in this study were analyzed using an analysis of variance (ANOVA) appropriate for a randomized complete block split plot design with NaCl concentration as the main plot, genotype as the subplots and replications as blocks. The Statistical Analysis System (Costat System for Windows, version 6.311) was used for analysis of variance of all data. Regression analyses were performed to investigate the relationship between grain yield per plant and seedling growth parameters at 14 days from sowing. Regression analyses were performed using the Microsoft Excel 2007.

Results

Highly significant differences among salinity concentrations and genotypes ($P<0.001$ or $P<0.01$) in germination and seedling parameters were observed in this study. The interaction between salinity and genotypes was also highly significant ($P<0.001$ or $P<0.05$) for seedling parameters measured at 14 days from sowing, indicating there are differential responses of genotypes to salinity from low to high levels (Table 1). Thus, the relationships between the seedling parameters and salt tolerance (i.e. grain yield) at 40, 80 and 160 mM NaCl are presented and discussed here.

Table 1. F-tests and *P* values of main effects of salinity and genotypes and their interactions for germination parameters and seedling parameters measured at 14 days from sowing.

Source	df	Germination parameters		Seedling parameters at 14 days from sowing			
		Germination percentage	Germination index	Shoot height	Shoot dry weight	Root dry weight	Shoot/ root ratio
Salinity (S)	3	12.8**	2520.7***	226.6***	318.2***	25.4***	8.6**
Genotypes (G)	9	21.2***	34.4***	14.2***	22.7***	8.4***	14.5***
S x G	27	1.0ns	1.3ns	2.8***	5.7***	1.7*	4.3***

Seed germination

Generally, it was obvious that salinity concentrations slightly affected the final germination percentage (Figure 1). For example, at 40, 80 and 160 mM NaCl, final germination percentage was reduced by only 0.7, 3.6 and 5.7%, respectively, as compared with 0 mM NaCl. Moreover, all genotypes attained more than 90% final germination percentage even with higher level of salt concentration (160 mM NaCl) except two salt-sensitive genotypes (Sahel 1 and Triso), which achieved 80% of the final germination percentage. As shown in Figure 1, the seeds of all genotypes germinated satisfactorily on the 4th day in 0 mM NaCl and low salinity concentration (40 mM NaCl), while on the 5th and 6th day in the medium (80 mM NaCl) and high (160 mM NaCl) salinity concentrations, respectively, i.e. germination of seeds was retarded by 1 and 2 days at medium and high salinity concentrations, respectively, as compared to 0 mM NaCl.

At a given salinity concentration, all genotypes showed a similar pattern in the germination index (GI), even though there was a significant decrease in GI with the increase in salinity concentrations. A strong reduction in GI was observed at the high salinity concentration by 54.1% compared to 0 mM NaCl (Figure 2).

Seedling growth

Seedling growth parameters showed a much higher sensitivity to salt stress than those for seed germination. Height and dry weight of shoot, root dry weight, and shoot/root ratio decreased significantly with increasing salinity concentrations. However, the low salinity concentration reduced these parameters to a lesser degree than moderate and high salinity concentrations (Figure 3). Furthermore, salinity affected shoot growth more than that of roots. At 40, 80 and 160 mM NaCl, for example, shoot height was reduced by 12, 22 and 38%, shoot dry weight was reduced by 20, 35 and 53%, root dry weight was reduced by 9, 19 and 34%, and shoot/root ratio was reduced by 12, 19 and 27%, respectively, as compared with those that of 0 mM NaCl (Figure 3).

The relative salt tolerance indices for shoot and root parameters varied among genotypes (Table 1). Furthermore, the variation of the salt tolerance indices among genotypes increased from low to high salinity concentrations (Table 2). For instance, the salt tolerance indices at low and high salinity concentrations ranged from 0.78 to 0.97 and from 0.48 to 0.78 for shoot height, and from 0.76 to 1.08 and from 0.48 to 1.42 for shoot/root ratios among genotypes, respectively. The salt tolerance indices for shoot and root dry weights ranged from 0.71 to 1.00 and from 0.83 to 1.00 at low salinity concentration, whereas the indices of both parameters ranged from 0.34 to 0.72 and from 0.50 to 0.81 at high salinity concentration among genotypes, respectively.

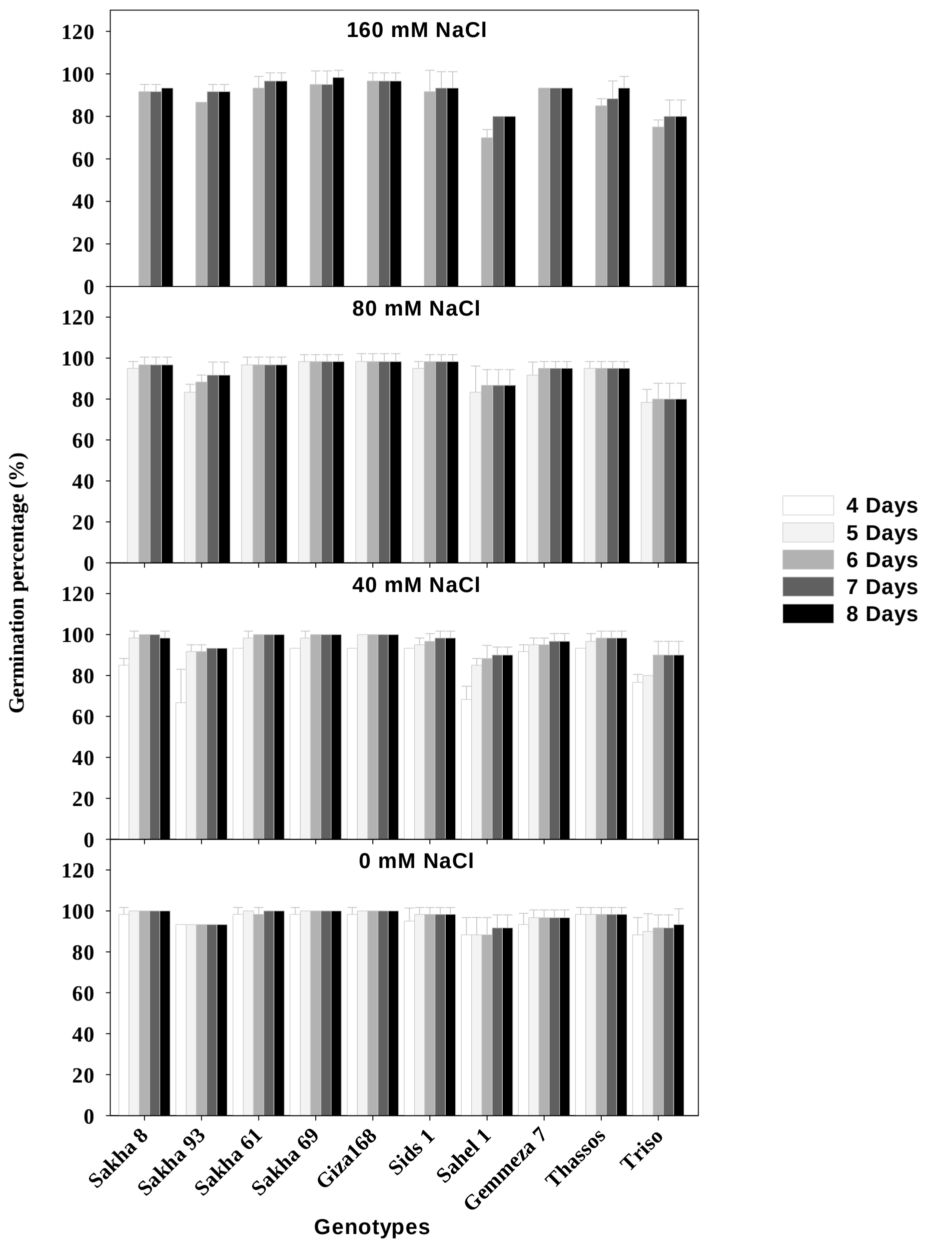

Figure 1. Effect of different salinity concentrations (mM) on germination percentage of 10 wheat genotypes. Error bars represent standard deviations of the mean of four replicates. Error bars are not shown if smaller than symbols.

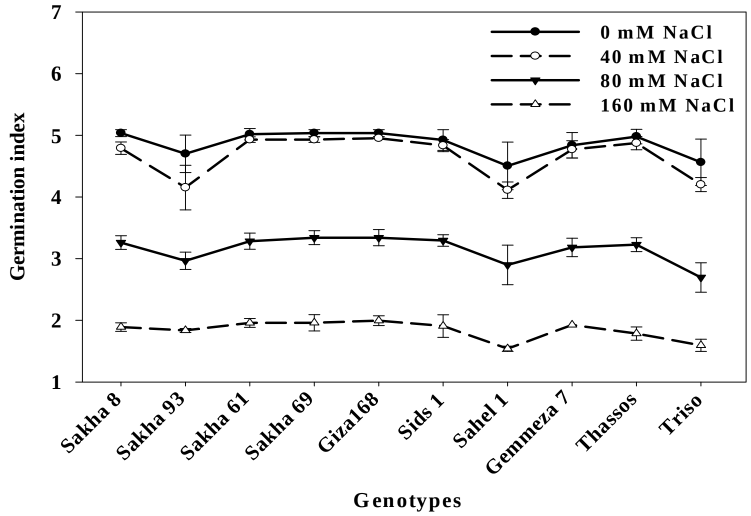

Figure 2. Effect of different salinity concentrations (mM) on germination index of 10 wheat genotypes. Error bars represent standard deviations of the mean of four replicates. Error bars are not shown if smaller than symbols.

Table 2. Salt tolerance indices for seedling growth parameters (shoot height, shoot dry weight, root dry weight and shoot/root ratio) at 14 days from sowing for 10 wheat genotypes under different salinity concentrations.

Genotypes	Salinity levels (mM NaCl)	Shoot height	Shoot dry weight	Root dry weight	Shoot/root ratio
	40	0.89	0.97	0.90	1.08
Sakha 8	80	0.85	0.84	0.77	1.09
	160	0.73	0.71	0.50	1.42
	40	0.92	1.00	0.97	1.03
Sakha 93	80	0.93	0.92	0.94	0.98
	160	0.78	0.72	0.81	0.89
	40	0.82	0.72	0.94	0.77
Sakha 61	80	0.67	0.56	0.88	0.64
	160	0.51	0.34	0.72	0.48
	40	0.78	0.75	0.87	0.86
Sakha 69	80	0.75	0.56	0.71	0.79
	160	0.55	0.38	0.71	0.53
	40	0.89	0.76	0.88	0.86
Giza 168	80	0.82	0.59	0.73	0.81
	160	0.67	0.41	0.52	0.80
	40	0.87	0.77	0.83	0.93
Sids 1	80	0.76	0.61	0.60	1.02
	160	0.60	0.42	0.50	0.84
	40	0.97	0.84	0.96	0.87
Sahel 1	80	0.82	0.68	0.85	0.80
	160	0.60	0.52	0.65	0.80
	40	0.95	0.84	1.00	0.84
Gemmeza 7	80	0.80	0.64	0.81	0.79
	160	0.69	0.56	0.77	0.73
	40	0.84	0.71	0.93	0.76
Thassos	80	0.76	0.55	0.97	0.57
	160	0.63	0.37	0.73	0.50
	40	0.84	0.71	0.85	0.84
Triso	80	0.63	0.60	0.85	0.70
	160	0.48	0.37	0.74	0.50

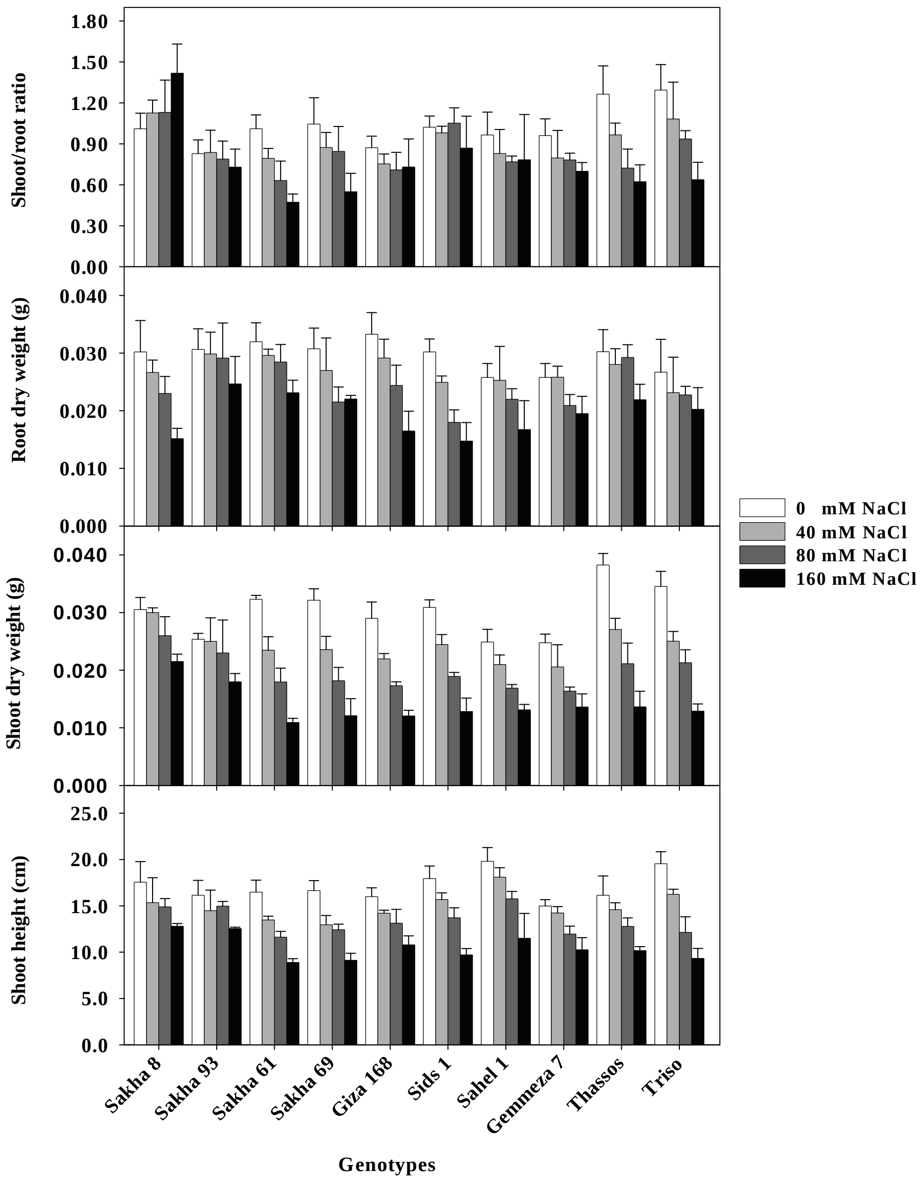

Figure 3. Effect of different salinity concentrations (mM) on seedling growth parameters (shoot height, shoot dry weight, root dry weight and shoot/root ratio) at 14 days from sowing for 10 wheat genotypes. Error bars represent standard deviations of the mean of four replicates. Error bars are not shown if smaller than symbols.

Based on simultaneous analysis of the means of salt tolerance indices in shoot height, dry weight of shoot and root, and shoot/root ratios using single-linked cluster analysis, the genotypes were divided into three cluster group at low salinity concentration and four cluster group at medium and high salinity concentrations in shoot height (Table 3). The genotypes were divided into three, four and five cluster groups at low, moderate and high salinity concentrations, respectively, in dry weight of shoot and root (Tables 4 and 5). However, the genotypes were divided into four cluster group at low salinity concentration and five cluster group at moderate and high salinity concentrations in shoot/root ratios (Table 6). Based on height and dry weight of shoot and shoot/root ratios, Sakha 8 and Sakha 93 were ranked as the most tolerant genotypes, whereas Sakha 61, Sakha 69, Thassos and Triso were ranked as the least tolerant among all genotypes. Sids 1, Giza 168, Gemmeza 7 and Sahel 1 were intermediate between the most and least tolerant with the exception of Gemmeza 7, which was ranked as tolerant genotype based on shoot height. Importantly, height and dry weight of shoot, and shoot/root ratios ranked the genotypes in the same order as their salt-tolerance ranking based on grain yield per plant, whereas the ranking genotypes in terms of root dry weight did not match well with their ranking in terms of grain yield per plant (Tables 3-6). For example, Sakha 8 was ranked as the most tolerant genotype based on grain yield whereas it was ranked as the least tolerant among all genotypes based on root dry weight and vice versa for Thassos (Table 4).

Table 3. Rankings of 10 wheat genotypes for their relative salt tolerance in terms of shoot height at 14 days from sowing in a cluster analysis (Single-link cluster analysis).

Genotypes	Salinity levels (mM NaCl)			Sum	Genotypes ranking	Tolerant degree based on shoot height	Tolerant degree based on grain yield¶
	40	80	160				
Sakha 93	1	1	1	3	1	Tolerant	Tolerant
Sakha 8	2	2	1	5	2	Tolerant	Tolerant
Gemmeza 7	1	2	2	5	2	Tolerant	Moderate
Giza 168	2	2	2	6	3	Moderate	Moderate
Sahel 1	1	2	3	6	3	Moderate	Sensitive
Sids 1	2	3	3	8	4	Moderate	Moderate
Thassos	3	3	3	9	5	Sensitive	Sensitive
Sakha 69	3	3	4	10	6	Sensitive	Moderate
Triso	3	4	4	11	7	Sensitive	Sensitive
Sakha 61	3	4	4	11	7	Sensitive	Sensitive

Source: El-Hendawy et al. (2005a).

Table 4. Rankings of 10 wheat genotypes for their relative salt tolerance in terms of shoot dry weight at 14 days from sowing in a cluster analysis (Single-link cluster analysis).

Genotypes	Salinity levels (mM NaCl)			Sum	Genotypes ranking	Tolerant degree based on shoot dry weight	Tolerant degree based on grain yield¶
	40	80	160				
Sakha 93	1	1	1	3	1	Tolerant	Tolerant
Sakha 8	1	2	1	4	2	Tolerant	Tolerant
Sahel 1	2	3	2	7	3	Moderate	Sensitive
Gemmeza 7	2	3	2	7	3	Moderate	Moderate
Giza 168	3	4	3	10	4	Moderate	Moderate
Sids 1	3	4	3	10	4	Moderate	Moderate
Thassos	3	4	4	11	5	Sensitive	Sensitive
Triso	3	4	4	11	5	Sensitive	Sensitive
Sakha 69	3	4	4	11	5	Sensitive	Moderate
Sakha 61	3	4	5	12	6	Sensitive	Sensitive

Source: El-Hendawy et al. (2005a).

Table 5. Rankings of 10 wheat genotypes for their relative salt tolerance in terms of root dry weight at 14 days from sowing in a cluster analysis (Single-link cluster analysis).

Genotypes	Salinity levels (mM NaCl)			Sum	Genotypes ranking	Tolerant degree based on root dry weight	Tolerant degree based on grain yield¶
	40	80	160				
Sakha 93	1	1	1	3	1	Tolerant	Tolerant
Thassos	1	1	3	5	2	Tolerant	Sensitive
Gemmeza 7	1	2	3	6	3	Moderate	Moderate
Sakha 61	1	2	3	6	3	Moderate	Sensitive
Sahel 1	1	2	4	7	4	Moderate	Sensitive
Triso	3	2	3	8	5	Sensitive	Sensitive
Sakha 69	2	3	3	8	5	Sensitive	Moderate
Giza 168	2	3	5	10	6	Sensitive	Moderate
Sakha 8	2	3	5	10	6	Sensitive	Tolerant
Sids 1	3	4	5	12	7	Sensitive	Moderate

Source: El-Hendawy et al. (2005a).

Table 6. Rankings of 10 wheat genotypes for their relative salt tolerance in terms of shoot/root ratio basis on dry weight at 10 days from sowing in a cluster analysis (Single-link cluster analysis).

Genotypes	Salinity levels (mM NaCl)			Sum	Genotypes ranking	Tolerant degree based on root dry weight	Tolerant degree based on grain yield¶
	40	80	160				
Sakha 8	1	1	1	3	1	Tolerant	Tolerant
Sakha 93	1	2	2	5	2	Tolerant	Tolerant
Sids 1	2	1	3	6	3	Moderate	Moderate
Sahel 1	3	3	3	9	4	Moderate	Sensitive
Giza 168	3	3	3	9	4	Moderate	Moderate
Gemmeza 7	3	3	4	10	5	Moderate	Moderate
Sakha 69	3	3	5	11	6	Sensitive	Moderate
Sakha 61	4	3	5	12	7	Sensitive	Sensitive
Triso	3	4	5	12	7	Sensitive	Sensitive
Thassos	4	5	5	14	8	Sensitive	Sensitive

Source: El-Hendawy et al. (2005a).

Discussion

Seed germination and seedling establishment are the two critical steps in life cycle of wheat crop. The loss of plant stand causes a reduction in yield sink capacity by a decrease in plant density. Thus, screening of genotypes for salt tolerance at these two early stages may important for screening salt tolerance as a considerable saving in time. However, the salt tolerance at early growth stages does not always correlate with that at the following growth stages (Mass and Grieve, 1994; Zeng et al., 2002; Ferdose et al., 2009). In this study, therefore, we focused on evaluating the potential of evaluating the salt tolerance in wheat genotypes at early growth stage, the ranking of genotypes for salt tolerance in terms of parameters measured at seedling stages in order to compare their rankings with those for grain yield at the final harvest. Ranking of salt tolerance of the 10 wheat genotypes based on the grain yield per plant was reported by El-Hendawy et al. (2005a). Briefly, among the Egyptian wheat genotypes, Sakha 8 and Sakha 93 were ranked as the most salt-tolerant genotypes compared with the others. Sahel 1 and Sakha 61 from Egypt and Thassos and Triso from Germany were the most salt sensitive genotypes. Giza 168, Gemmeza 7, Sids 1 and Sakha 69 were intermediate between the most and least tolerant (El-Hendawy et al., 2005a).

The seeds of different genotypes of crops may germinate adequately under salt stress. Nevertheless, the seedling may not be established well for further growth. This phenomenon has also been observed in triticale (Abdul Karim et al., 1992) and wheat (Raiaz-Ahmed et al., 2001; Kaya et al., 2008). Thus, the authors suggested that seedling parameters are the most important criterion for the screening of genotypes for salt tolerance at the early growth stages. The present study clearly showed that salinity had greater inhibitory effects on seedling growth than germination, which revealed substantial genotypic variation in salt tolerance among genotypes (Figure 3). The significant reduction in seedling growth by salinity may be due to toxic effects of NaCl and unbalanced nutrient uptake by the seedlings. These deleterious effects of salinity may result in a significant decrease in photosynthesis rate and increases in respiration rate of seedlings that lead to a shortage of assimilate to the developing organs and may slow down growth or stop it entirely (El-Hendawy et al., 2005b).

However, the question may arise here: which seedling parameters can be used for an accurate ranking of genotypes as such as their rankings in terms of grain yield? Results of the present study have shown that height and dry weight of shoot, and the shoot/root ratio demonstrated the greatest variation in the salt tolerance among genotypes. Importantly, the order of genotypes for these parameters almost matched with their ranking in terms of grain yield. However, the order of genotypes for root dry weight did not match well with their salt tolerance as ranked using grain yield (Tables 3-6). This indicates that measurements derived from the shoots were generally more effective as screening criteria than those from the roots, which may be due to the osmotic adjustment occurring in roots more rapidly, but losing turgor more slowly than shoots (Shalhevet et al., 1995; Studer et al., 2007; Ferdose et al., 2009). Consequently the response of shoots to salinity was significantly stronger than the response of roots. These results were similar to the findings of Keiffer and Ungar (1997), Kaya et al. (2008), and Moud and Maghsoudi (2008). They found that the shoots of seedlings were more sensitive to salt stress than the roots. This is, indeed, contrary to the findings of Rahman et al. (2001), Jamil et al. (2006) and Ogawa et al. (2006), who found that root growth was more adversely affected by salinity than shoot growth. A reason for the discrepancy between these contrary findings may be found in the differences in the methods that were used to measure root especially when the roots were extracted from the soil to measure their characterizes. In general, the methods used to determine the aerial parts of plants may be more accurate than those used to determine the roots. For this reason, when shoot and root measurements are considered as selection criterion, we recommend that shoot parameters should be the primary selection criterion. Furthermore, it is vital that, in addition to choose the parameters for screening genotypes for salt tolerance, the selection program for salt tolerance must take into account the accuracy of the methods used to measure these parameters.

To confirm these hypotheses, the various regression equations were evaluated to determine the relationship between grain yield per plant and seedling parameters. Based on R^2 values, linear order equations were found to fit these data best, with coefficient of determination of 0.56 ($P<0.01$; Figure 4), 0.63 ($P<0.001$; Figure 5), 0.25 ($P<0.2$; Figure 5) and 0.31 ($P<0.05$; Figure 6) for shoot height, shoot dry weight, root dry weight and shoot/root ratio, respectively. Again, the highly significant correlations between grain yield per plant and shoot parameters (height and dry weight of shoots) at the seedling stage further confirmed the importance of these parameters as useful selection criteria for screening the salt tolerance in terms of grain yield among genotypes.

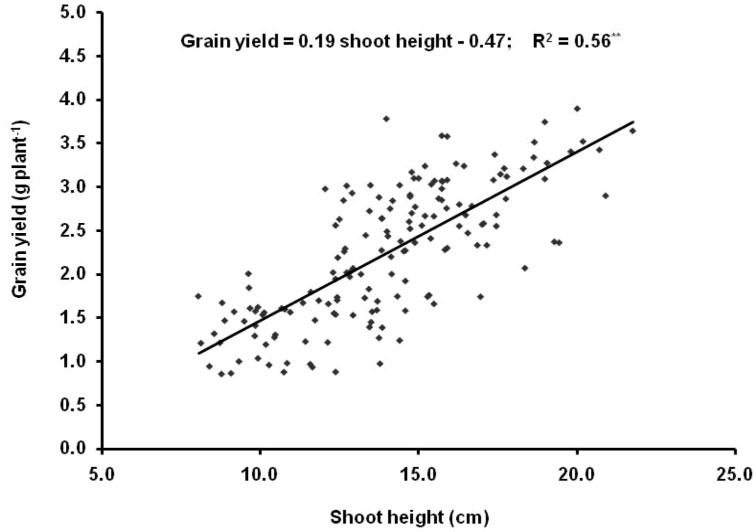

Figure 4. Relationship between grain yield per plant and shoot height measured at 14 days from sowing. Each point represents a replicate. A linear equation best fit the relations between the variables; ** indicate significant at 0.01 *P* level. Grain yield donated from El-Hendawy et al. (2005a).

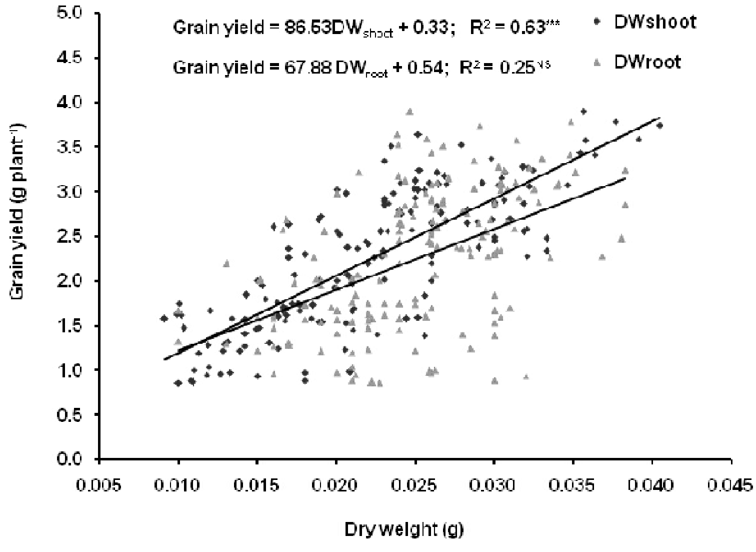

Figure 5. Relationship between grain yield per plant and shoot dry weight (DW_{shoot}) and root dry weight (DW_{root}) measured at 14 days from sowing. Each point represents a replicate. A linear equation best fit the relations between the variables; *** and NS indicate significant at 0.01 *P* level and non significant, respectively. Grain yield donated from El-Hendawy et al. (2005a).

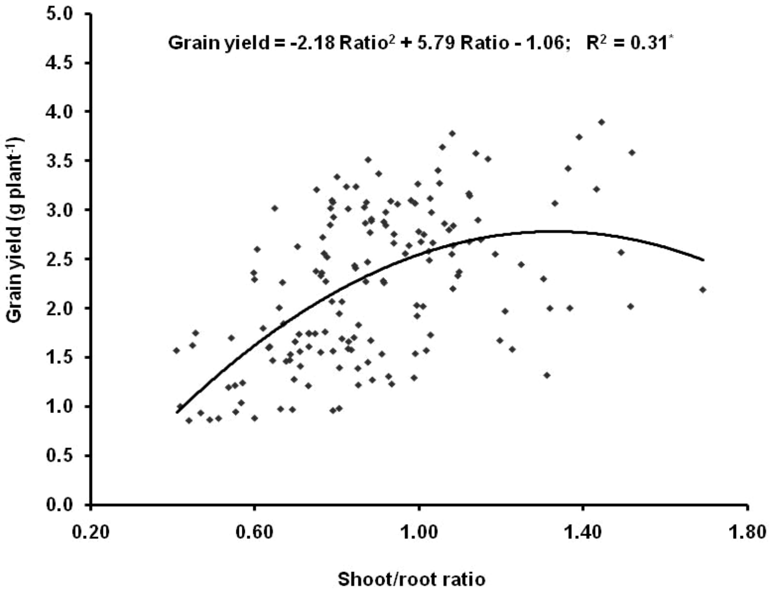

Figure 6. Relationship between grain yield per plant and shoot/root ratio. Each point represents a replicate. A quadratic equation best fit the relations between the variables; * indicate significance at the 0.05 *P* level. Grain yield donated from El-Hendawy et al. (2005a).

Interestingly, the variations of the salt tolerance indices among genotypes were less at low salinity concentration than at high salinity concentration (Table 2). This result suggests that the selection criteria can be considered appropriate for screening wheat genotypes only when they were measured under high salinity concentrations. Similarly, Tajbakhsh et al. (2006) reported that salinity stress of 160 mmol/L or 320 mmol/L NaCl for 3 or 4 weeks would be suitable for selecting salinity tolerant barley cultivars because this treatment can clearly separate tolerant and susceptible cultivars. Krishnamurthy et al. (2007) also reported that measuring the biomass production of sorghum genotypes at 39 days after sowing following saturation of the soil to field capacity with a 250 mM NaCl solution has provided an accurate criterion for tolerance of the relative biomass production in the early growth stage under saline conditions, and has revealed substantial variation among genotypes. These results are confirmed by the correlations between grain yield and different seedling parameters under different salinity levels (Table 7). Based on R^2 values, the most useful selection criteria at seedling stage (height and dry weight of shoots) were related highly significant with grain yield per plant under high salinity concentration, whereas these relations were not significant under low salinity concentrations (Table 7).

The results at the germination stage indicate that germination index was more sensitive to salinity than the final germination percentage, which is in agreement with the observations of Alam et al. (2001) in wheat, and Atak et al. (2006) in triticale. They observed that NaCl did not adversely affect final germination percentage, but delayed germination at higher concentrations of NaCl. In general, salinity stress can affect seed germination through osmotic effects (Welbaum et al., 1990) or by ion toxicity (Huang and Reddman, 1995), but evidence suggests that the low water potential of the germination medium is a major limiting factor (Bradford, 1995). Therefore, the non-significant effects of salinity on final germination percentage even at high salinity concentrations in this study may be due to the final soil water content in the soil being almost consistent during the experimental period (the final soil water content was 25% on a dry soil basis, see Materials and Methods). Thus, the main reason for reducing germination percentage under salinity conditions (osmotic effects) did not seem to have any effect upon final percentage of seeds germinating in this study. Therefore, the final germination percentage failed to distinguish the salt-tolerance differences among genotypes under those conditions, where water is not limiting factor as such as may found under field conditions.

Table 7. Regression equations and correlation coefficients between grain yield per plant (Y) and seedling parameters at 14 days from sowing (X) at different salinity levels.

Parameters	Salinity levels (mM NaCl)	regression equations	R^2
Shoot height	40	Y = 0.003X + 2.48	0.001^{ns}
	80	Y = 0.13X + 0.17	0.21^{*}
	160	Y = 0.16X – 0.37	0.29^{*}
Shoot dry weight	40	Y =17.59X + 2.09	0.02^{ns}
	80	Y = 60.40X + 0.59	0.22^{*}
	160	Y = 90.91X + 0.24	0.46^{**}
Root dry weight	40	Y = – 21.42X + 3.10	0.04^{ns}
	80	Y = 6.61X + 1.63	0.03^{ns}
	160	Y = 9.77X + 1.33	0.08^{ns}
Shoot/root ratio	40	Y = 0.60X + 1.97	0.06^{ns}
	80	Y = 0.73X + 1.17	0.08^{ns}
	160	Y = 0.61X + 1.05	0.16^{*}

$^{ns, *, **}$ not significant, and significant at the 0.05 and 0.01 probability levels, respectively.

Conclusion

Overall, it can be concluded that substantial variation in salt tolerance among wheat genotypes at the seedling stage was found in this study. Highly significant correlations between grain yield and shoot parameters (height and dry weight) confirmed that it is important to use both parameters as useful selection criteria for screening the salt tolerance in terms of grain yield among genotypes at early vegetative growth stage. Most importantly, both parameters can be considered for screening wheat genotypes at high salinity concentrations.

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