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Determination of the Salt Tolerance of Some Barley Genotypes and the Characteristics Affecting Tolerance

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Abstract: The salt (NaCl) tolerance of 8 barley genotypes was investigated. Plants were grown hyroponically in Hoagland solution at 5 different NaCl concentrations. Germination percentage, shoot and root length, shoot and root dry weight, salt tolerance percentage, and K and Na concentrations in the shoots and roots were evaluated. Salt tolerance percentage, which is calculated from the germination percentage and dry weight production, was the most reliable criterion. On the other hand, with some exceptions, high K concentration and K/Na ratios were other potential criteria. Erginel-90 and WBELT-10 showed high levels of tolerance; and Anadolu-86, Kıral-97 and Karatay-94 showed medium levels. Tokak-157/37 and Hamidiye-85 were the most susceptible genotypes to NaCl.

Key Words: barley (*Hordeum vulgare* L.), salinity, NaCl, tolerance

Bazı Arpa Genotiplerinin Tuza Toleranslarının ve Toleransı Etkileyen Özelliklerin Belirlenmesi

Özet: Bu çalışmada Hoagland Çözeltisi ve NaCl kullanılarak beş farklı tuz konsantrasyonunda 8 adet arpa genotipinin tuza toleransları incelenmiştir. Değerlendirmeler çimlenme yüzdesi, sap ve kök uzunlukları ile kuru ağırlıkları, tuza tolerans yüzdesi, K ve Na konsantrasyonları üzerinde yapılmıştır. Çimlenme yüzdesi ve kuru ağırlığın bir sonucu olan tuza tolerans yüzdesi en güvenilir kriter olarak belirlenmiştir. Yüksek K konsantrasyonu ve K/Na oranının bazı istisnalarla birlikte diğer potansiyel seleksiyon kriterleri olduğu görülmüştür. Erginel-90 ve WBELT-10 yüksek, Anadolu-86, Kıral-97 ve Karatay-94 orta seviyede toleranslı, Tokak-157/37 ve Hamidiye-85 ise tuzluluğa karşı duyarlı bulunmuştur.

Anahtar Sözcükler: arpa (*Hordeum vulgare* L.), tuzluluk, NaCl, tolerans

Introduction

Saline soils are widespread in arid and semiarid regions of the world. This problem may be a result of basins with limited or no access to rivers due to diverse soil properties, unsuitable irrigation practices, poor drainage and high evaporation. Salinity is one of the main problems that negatively affect soil fertility and limit plant production (De Sigmond, 1924; Richards, 1954).

Salt tolerance is a complex trait involving different mechanisms, and is defined as the ability of the plant to survive under salinity and complete the growth cycle with an acceptable growth and yield. The factors affecting plant growth under salinity may be evaluated in 3 groups: i) water stress, ii) ion toxicity, iii) problems in nutrient uptake and translocation to green plant parts, and, as a result, disorders in cells due to disruption of ionic balances such as in the case of K^+ and Ca^{++}. Under salt stress, physiological drought may play an important role by limiting water uptake from the soil. On the other hand, excess salt uptake by plants disrupts cellular functions and damages physiological processes such as photosynthesis and respiration (Leopold and Willing, 1984; Marschner, 1995).

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The possible mechanisms in the salt tolerance of plants may involve: i) no or less uptake of salt into the plant, ii) tissue tolerance, iii) accumulation of salt in vacuoles without any physiological interference, iv) ion discrimination, such as K^+, Na^+, Cl^- and $SO_4^=$ during uptake by roots and translocation to shoots, v) different biochemical processes such as the production of some enzymes, hormones, antioxidants, etc. (Pitman, 1984; Wise and Naylor, 1987; Gorham and Jones, 1990; Spychalla and Desborough, 1990; Begum and Karmoker, 1999). One or more of these mechanisms may be responsible for variations in the salt tolerance of plant genotypes and species.

Salinity can be alleviated through either soil reclamation or growing tolerant crops. However, soil reclamation is a very expensive process, and hence the cultivation of tolerant species and varieties is the most practical solution when the salinity is low. It is well known that there are significant genotypic differences with respect to salt tolerance between and within plant species (Rana, 1986; Bozcuk, 1991; Suhayda et al., 1992; Açıkgöz and Gevrek, 1994; Zhong et al., 1995; Ekiz et al., 1999).

Due to increasing salinity problems both in Turkey and in many other countries around the world, breeding for salinity needs more attention. Besides genetic resources, the use of efficient selection criteria would help breeders. However, it is difficult to say that the breeders have efficient selection criteria and tools for improvement of salt tolerant varieties. Rather than a long-term breeding program, the determination of more tolerant varieties to grow in saline soils may be a short-term solution.

In this study, genetic variations in the salt tolerance of barley genotypes were investigated by a nutrient solution experiment with different NaCl concentrations. In addition, the most efficient selection criteria were determined.

Materials and Methods

Eight barley genotypes (Tokak-157/37, Hamidiye-85, Erginel-90, Anadolu-86, Bülbül-89, Kıral-97, Karatay-94 and WBELT-10) were grown in 1/3 strength Hoagland solution at the Bahri Dağdaş International Winter Cereal Research Center in Konya between 1994 and 1999. Five salt (NaCl) concentrations, 3.4 mM (S_1), 59.3 mM (S_2), 133.3 mM (S_3), 216.6 mM (S_4) and 314.5 mM (S_5), were used. The experimental design was a split plot with 4 replications; salt concentrations in the main plots, and genotypes in the sub-plots.

Growth Conditions

Fifteen seeds from each genotype were planted in the cells (2.5 x 4 cm) of a plastic ice-holder fitted on a styrofoam block. The block was continuously floating on 15 l of diluted Hoagland Solution. Each cell was evaluated as a single replication. Illumination was provided by fluorescent lamps giving a light intensity of 325 mmol $m^{-2}s^{-1}$ and the photoperiod was 14 h per day (6:00-20:00). Air temperature was adjusted to +20 ºC, and water temperature was kept steady at 20-24 ºC by an aquarium-type heater. The aeration of the nutrient solution was provided by an aquarium pump. The nutrient solution level was checked every day, and changes in EC values were determined every 3 days.

Traits measured

Germination percentage: Seven days after seeds were put into the cells, germinated seeds were counted and the germination percentage was calculated. Then 4 seedlings were left in each cell to be evaluated for other traits.

Shoot and root length: Seventeen days after planting, the plants were separated into shoots and roots. The distances from crown to leaf tip and root tip were measured as shoot length and root length, respectively. The mean values in each replication were used for statistical analysis.

Shoot and root dry weight: The roots and shoots of plants in each replication were dried at 70 ^{O}C until a constant weight was reached. Then root and shoot dry weights were measured and the dry weight of root and shoot per plant was calculated by dividing the total weight by the number of plants.

Shoot/Root ratio: This was calculated for both length and weight by dividing shoot values by root values.

Determination of K and Na Concentrations: Root and shoot samples were wet digested with a HNO_3 and $HClO_4$ acid mixture and analyzed by a flame photometer (Jenway PFP7) as described by Kacar (1972).

Salt tolerance index: This was calculated as total plant (shoot + root) dry weight obtained from 100 seeds grown on different salt concentrations compared to total plant dry weight obtained on normal concentration {[STI

= (TDW at S_x / TDW at S_1) x 100], STI = salt tolerance index, TDW = total dry weight, S_1 = control treatment, S_x = x treatment}.

Results

Germination percentage

Germination percentages declined sharply with S_4 and S_5 treatments. At these NaCl concentrations, differences among the genotypes were significantly different. Erginel-90 and WBELT-10 had germination percentages higher than 50% even with the S_5 treatment, while Tokak-157/37 and Anadolu-86 had lower germination percentages with the same NaCl treatment. The germination percentages of Tokak-157/37 and Anadolu-86 were relatively high with the S_4 treatment. These results showed that S_4 and S_5 treatments can be used effectively to identify moderately and highly resistant genotypes, respectively (Table 1). Hamidiye-85 was the only genotype that did not germinate at the highest NaCl concentration.

Shoot and root length and Shoot/Root ratio

There were significant differences between genotypes in terms of shoot and root lengths. Increasing NaCl treatments resulted in a significant decrease in shoot elongation. Compared to the control (S_1) plants, longer root lengths were recorded at higher salt concentrations except with the S_5 treatment (Table 2).

The shoot/root ratio of the more salt tolerant genotypes was 1.5-2.0 at the highest NaCl concentration. The decrease in shoot elongation starting from the S_2 treatment was considered an indicator that shoot growth was affected more quickly compared with the roots.

Shoot and root weight and Shoot/Root ratio

Similar to the shoot elongation, shoot weight also decreased, starting from the S_2 treatment. In accordance with the root elongation, average root dry matter production was significantly higher with the S_3 and S_4 treatments compared with S_5 and S_2 but was dramatically decreased by the S_5 treatment. The average shoot/root ratio was 5.7 with S_5 and gradually decreased to 2.9 with increasing NaCl treatments. The main reason for this is mostly attributable to the rapid reduction of shoot dry matter production as a result of increasing NaCl supply (Table 3).

K and Na concentration and K/Na ratio

The S_1 treatment gave high K and low Na concentrations (K 13.4-15.8%, Na 0.14-0.19% and K/Na ratio 79.0-111.0% in the shoots; K 13.2-15.2%, Na 0.78-1.11% and K/Na ratio 12.3-18.6% in the roots). However, with increases in salt concentrations K uptake decreased while Na uptake increased rapidly (Table 4). The S_5 treatment gave K and Na concentrations and K/Na ratios in the shoots of 0.0-5.9%, 0.00-8.30%

Table 1. Germination percentage of 8 barley genotypes germinated under different NaCl treatments (S_1: 3.42 mM, S_2: 59.3 mM, S_3: 133.3 mM, S_4: 216.6 mM, S_5: 314.5 mM).

Genotypes	Germination Percentage (%)				
	S_1	S_2	S_3	S_4	S_5
Tokak-157/37	97	96	92	78	12
Hamidiye-85	92	83	81	58	0
Erginel-90	100	100	96	92	73
Anadolu-86	97	92	92	80	28
Bülbül-89	85	95	87	39	21
Kıral-97	95	88	90	73	45
Karatay-94	85	93	90	62	28
WBELT-10	100	95	97	87	65
Mean	94	93	91	71	34
LSD(5%)=	8	6	9	16	15

CV = 10 LSD(5%) = 12, for genotype x salt concentrations **
6, for salt concentrations **

** significant at P = 0.01 level.

Table 2. Shoot and root lengths and shoot/root ratios of 8 barley genotypes grown with different NaCl treatments (S_1: 3.42 mM, S_2: 59.3 mM, S_3: 133.3 mM, S_4: 216.6 mM, S_5: 314.5 mM) for 17 days.

	S_1			S_2			S_3			S_4			S_5		
Genotypes	S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R
							(cm)								
Tokak-157/37	34.3	7.8	4.4	26.0	11.6	2.3	22.7	18.5	1.2	18.0	14.5	1.2	9.7	6.3	1.5
Hamidiye-85	26.6	7.5	3.6	24.7	12.2	2.0	19.4	13.9	1.4	15.6	11.5	1.4	0.0	0.0	0.0
Erginel-90	26.0	8.2	3.2	23.2	13.8	1.8	21.8	18.5	1.2	18.9	16.1	1.2	12.5	7.0	1.8
Anadolu-86	30.9	7.3	4.3	29.1	12.3	2.4	22.2	17.8	1.3	18.0	13.0	1.4	9.5	4.7	2.0
Bülbül-89	31.1	7.1	4.6	31.0	12.2	2.6	24.1	17.4	1.4	17.2	9.3	1.9	12.9	6.4	2.0
Kıral-97	23.3	5.5	4.4	21.3	9.8	2.2	17.6	14.0	1.3	16.4	11.8	1.4	10.4	5.4	1.9
Karatay-94	27.6	7.3	3.8	22.2	11.6	1.9	17.7	14.4	1.2	15.8	12.1	1.3	11.3	6.0	1.9
WBELT-10	26.0	5.9	4.5	21.1	9.9	2.2	19.2	12.9	1.5	15.5	11.3	1.4	10.3	6.9	1.5
Mean	28.2	7.1	4.1	24.8	11.7	2.2	20.6	15.9	1.3	16.9	12.4	1.4	9.6	5.3	1.6
LSD $_{(5\%)}$ =	4.6	1.8	1.0	3.2	1.3	0.3	2.0	2.0	0.2	1.7	2.3	0.3	1.1	0.9	0.3
CV = 10 Shoot, 11 Root, 17 Shoot/Root							LSD $_{(5\%)}$ = 2.67 S**, 1.66 R**, 0.49 S/R** (for interactions)								

** significant at P = 0.01 level. S: Shoot R: Root S/R: Shoot to root ratio

Table 3. Shoot and root dry matter production of 8 barley genotypes grown with different NaCl treatments treatments (S_1: 3.42 mM, S_2: 59.3 mM, S_3: 133.3 mM, S_4: 216.6 mM, S_5: 314.5 mM) for 17 days.

	S_1			S_2			S_3			S_4			S_5		
Genotypes	S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R
							(mg plant^{-1})								
Tokak-157/37	38.4	7.1	5.4	32.5	6.6	4.9	35.8	8.5	4.2	29.0	8.9	3.3	21.0	6.0	3.5
Hamidiye-85	25.4	6.0	4.2	29.2	7.1	4.1	25.0	6.3	4.1	22.3	7.1	3.2	0.0	0.0	0.0
Erginel-90	28.9	4.9	6.0	29.3	5.2	5.7	28.0	5.9	4.8	25.4	7.1	3.6	17.6	5.1	3.6
Anadolu-86	35.2	6.3	5.5	36.5	7.5	4.9	32.6	8.5	3.8	28.9	7.8	3.8	16.3	5.5	3.0
Bülbül-89	31.4	5.4	5.9	37.5	7.6	5.0	32.8	8.1	4.1	24.5	6.7	3.7	21.4	6.0	3.6
Kıral-97	19.8	3.8	5.3	19.5	4.6	4.3	17.9	4.8	3.8	16.6	5.3	3.3	12.0	3.8	3.2
Karatay-94	30.0	5.1	5.9	25.7	5.9	4.4	19.6	4.7	4.2	20.9	5.8	3.7	19.6	5.3	3.7
WBELT-10	24.6	4.3	5.7	21.3	4.3	5.0	22.9	5.0	4.6	18.4	5.6	3.3	14.7	4.4	3.3
Mean	32.2	5.6	5.7	28.9	6.1	4.8	26.8	6.5	4.2	23.1	6.9	3.4	15.6	5.1	2.9
LSD (5%)=	6.6	0.9	0.9	4.9	1.0	0.5	3.0	1.0	0.5	3.3	1.4	0.5	2.8	0.9	0.4
CV =12 Shoot, 12 Root, 10 Shoot/Root							LSD(5%) = 4.14 S**, 0.99 R**, 0.56 S/R** (for interactions)								

** significant at P = 0.01 level. S: Shoot R: Root S/R: Shoot to root ratio

Table 4. K and Na concentrations (% of dry weight) of 8 barley genotypes grown with different NaCl treatments (S_1: 3.42 mM, S_2: 59.3 mM, S_3: 133.3 mM, S_4: 216.6 mM, S_5: 314.5 mM) for 17 days.

Genotypes		S_1			S_2			S_3			S_4			S_5		
		S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R	S	R	S/R
								(%)								
Tokak-157/37	K	14.2	14.3	1.0	10.5	9.6	1.1	9.1	8.3	1.2	7.3	1.7	4.3	5.1	3.1	1.7
	Na	0.18	0.78	0.23	3.80	9.50	0.40	5.90	14.30	0.42	5.80	8.40	0.69	4.50	15.50	0.29
	K/Na	83.0	17.9	-	2.8	1.0	-	1.6	0.6	-	1.3	0.2	-	1.1	0.2	-
Hamidiye-85	K	14.8	13.4	1.1	10.0	9.6	1.0	7.2	10.0	0.8	6.6	2.0	3.3	0.0	0.0	0.0
	Na	0.18	0.88	0.21	4.90	9.70	0.51	6.60	15.60	0.43	6.90	8.70	0.79	0.00	0.00	0.00
	K/Na	83.0	15.8	-	2.1	1.0	-	1.09	0.63	-	0.96	0.23	-	0.0	0.00	-
Erginel-90	K	14.6	13.2	1.1	10.2	10.1	1.0	8.4	9.8	1.0	6.6	2.8	2.4	5.8	2.7	2.2
	Na	0.17	1.11	0.15	3.60	9.00	0.41	6.10	15.30	0.40	6.10	9.00	0.68	5.70	16.30	0.35
	K/Na	90.0	12.3	-	2.8	1.2	-	1.4	0.6	-	1.1	0.3	-	1.0	0.2	-
Anadolu-86	K	13.4	13.3	1.0	11.0	8.6	1.3	9.2	7.0	1.3	7.0	2.0	3.5	4.1	2.0	2.1
	Na	0.17	0.92	0.18	3.30	8.60	0.39	5.70	13.80	0.42	5.80	11.10	0.52	6.40	14.30	0.45
	K/Na	83.0	14.2	-	3.4	1.0	-	1.6	0.5	-	1.2	0.2	-	0.6	0.1	-
Bülbül-89	K	14.5	14.4	1.0	10.5	9.3	1.1	8.2	7.1	1.2	6.0	2.8	2.2	5.3	2.2	2.4
	Na	0.19	0.84	0.23	3.90	7.50	0.52	6.50	14.30	0.45	7.10	13.90	0.51	5.30	14.20	0.38
	K/Na	79.0	17.3	-	2.8	1.2	-	1.3	0.5	-	0.9	0.2	-	1.0	0.2	-
Kıral-97	K	15.1	14.9	1.0	9.9	8.5	1.2	8.5	7.0	1.2	6.1	1.7	3.6	5.9	1.5	3.9
	Na	0.14	1.04	0.14	4.30	8.80	0.49	6.80	17.20	0.40	6.40	9.70	0.68	8.30	17.20	0.49
	K/Na	111.0	14.8	-	2.3	1.0	-	1.3	0.4	-	1.0	0.2	-	0.7	0.1	-
Karatay-94	K	13.7	14.8	0.9	9.2	7.0	1.3	7.6	5.2	1.5	6.1	1.7	3.6	5.3	2.1	2.6
	Na	0.16	1.04	0.15	4.20	9.40	0.45	6.30	15.10	0.42	6.50	9.60	0.69	6.30	20.00	0.32
	K/Na	88.0	14.6	-	2.2	0.8	-	1.2	0.4	-	1.0	0.2	-	0.8	0.1	-
WBELT-10	K	15.8	15.2	1.1	10.7	9.3	1.2	8.3	8.0	1.1	6.4	2.1	3.1	5.0	2.2	2.3
	Na	0.15	0.82	0.18	4.10	9.40	0.45	6.10	18.20	0.35	6.80	9.30	0.76	6.50	15.80	0.42
	K/Na	108.0	18.6	-	2.6	1.0	-	1.4	0.4	-	0.9	0.2	-	0.8	0.1	-
LSD (5%)=	K	0.9	2.2	0.2	1.6	1.7	0.3	1.0	2.3	0.3	0.8	0.5	1.3	0.7	0.3	1.2
	Na	0.00	0.20	0.04	0.80	1.30	0.09	1.00	3.00	0.07	0.60	2.40	0.20	0.70	1.50	0.06
	K/Na	11.3	2.6	-	0.4	0.2	-	0.3	0.09	-	0.2	0.04	-	0.2	0.01	-

CV = Shoot (K = 8, Na = 10, K/Na = 18), Root (K = 16, Na =13, K/Na = 23)
Shoot/Root (K = 24, Na = 16),

LSD(5%) : interactions tested were significant at P = 0.01 level
Shoot (K = 1.01, Na = 0.65, K/Na = 4.82), S/R (K = 0.75, Na = 0.09)
Root (K = 1.57, Na = 1.86, K/Na = 1.11)

S: Shoot R: Root S/R: Shoot to root ratio

and 0.0-1.1%, respectively, while K and Na concentrations and K/Na ratios in the roots were 0.0-3.1%, 0.00-20.00% and 0.0-0.2%, respectively. The highest K/Na ratios in the shoots and roots were obtained from Tokak-157/37, which may result from the population characteristics of this cultivar. Genotypes differed significantly in K and Na uptake, and K/Na ratios in both the shoots and roots.

Salt tolerance index

Although genotypes responded similarly during the first 3 salt treatments, significant differences among the genotypes were obvious with the S_4 and S_5 treatments, concerning the salt tolerance index of genotypes (Table 5). The salt tolerance index varied between 39 and 88% with S_4 and 0 and 50% with S_5. Erginel-90 (50%) and WBELT-10 (45%) were the best performing genotypes with the S_5 treatment; the other genotypes did not perform well -their salt tolerance indices ranged from 0% to 30%. The tolerance indices of genotypes with lower performances than Erginel-90 and WBELT-10, except for Bülbül-89, were above 50% with the S_4 treatment. Among these, with the S_5 treatment, Anadolu-86, Kıral-97 and Karatay-94 resulted in lower indices (18-30%), and so these genotypes were evaluated as moderately tolerant. Tokak-157/37 and Hamidiye-85 resulted in the lowest indices (0-7%), which were evaluated as the least tolerant genotypes.

Discussion

The results obtained in this study are consistent with previous findings that have indicated significant differences in the salt tolerance of barley genotypes and their different responses to increasing salt concentrations (Bozcuk, 1991; Mano and Takeda, 1997).

Even though salt tolerance during germination differs from that at later stages of plant development (Ashraf et al., 1997; Mano and Takeda, 1997), good germination under saline conditions is essential because it is the first stage of plant growth. From this perspective, it is clear that Erginel-90 and WBELT-10 with high germination percentages would have more advantages than the other genotypes that significantly lost their ability to germinate better.

Shoot and root lengths did not always relate to shoot and root weights. Although some genotypes had long

Table 5. The mean total (shoot and root) dry weight (TDW) and salt tolerance index (STI) values of 8 barley genotypes grown with different NaCl treatments (S_1: 3.4 mM, S_2: 59.3 mM, S_3: 133.3 mM, S_4: 216.6 mM, S_5: 314.5 mM).

	TDW (g)					STI (%)				
Genotypes	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5
Tokak-157/37	4.4	3.8	4.1	3.0	0.3	100	86	93	68	7
Hamidiye-85	2.9	3.0	2.6	1.7	0.0	100	103	90	59	0
Erginel-90	3.4	3.5	3.3	3.0	1.7	100	103	97	88	50
Anadolu-86	4.0	4.0	3.8	2.9	0.7	100	100	95	72	18
Bülbül-89	3.1	3.3	3.6	1.2	0.6	100	106	116	39	19
Kıral-97	2.3	2.2	2.1	1.6	0.7	100	96	91	70	30
Karatay-94	3.0	3.0	2.2	1.6	0.7	100	100	73	53	23
WBELT-10	2.9	2.4	2.7	2.1	1.3	100	83	93	72	45
Mean	3.3	3.2	3.1	2.1	0.7	100	96	93	64	23
LSD(5%) =	0.6	0.6	0.5	0.6	0.4	0	8	12	17	15
CV = 151LSD(5%) = 0.5 TDW **, 13 STI **										

** significant at P = 0.01 level. 1 for interactions of genotype x concentration

shoots and roots, thin and unbranched, they could not produce sufficient dry weight. In the contrast, some genotypes, such as Tokak-157/37 and Karatay-97, had relatively short shoot and root lengths, but high dry weight since they produced thick and branched shoots and roots. For this reason, when length and dry weight are considered as selection criteria, we advise that dry weight be the primary selection criterion. It is anticipated that in addition to higher dry weight, longer and stronger root and shoot development will allow more successful selection for high salt tolerance. However, as selection criteria, the length and weight measurements taken from single plants can be considered appropriate only when there is a high germination percentage. For these reasons, the salt tolerance index, which is a function of both germination percentage and total dry weight, was determined to be a more reliable selection criterion in this study.

The significant differences obtained for K and Na values could not explain genotypic differences regularly. However, differences in tolerance can be seen clearly when the K and Na values of the tolerant genotypes (Erginel-90 and WBELT-10) are compared with those of a susceptible genotype (Bülbül-89) in the S_4 and S_5 treatments. Bülbül-89 had high concentrations of Na in the shoots and roots, but low concentrations of K in the shoots. On the other hand, the tolerant genotypes (Erginel-90 and WBELT-10) tended to have higher shoot/root K ratios with S_5 treatment. However, significant differences between the K/Na ratios in the shoots and roots could not explain the differences in tolerance well. These results indicate that K and Na concentrations and their distributions in the shoots and roots may be important in terms of salt tolerance; however, it cannot be applied for all genotypes, and salt tolerance may have a close relationship with tissue tolerance. These findings are in agreement with those of other authors (Sharma, 1989; Gorham et al., 1990; Ayala et al., 1997), while conflicting data are also available (Forster et al., 1994; Pecetti and Gorham, 1997). Foster et al. (1994) explained that there were no significant differences in the shoot Na concentrations of the genotypes they used. Pecetti and Gorham (1997) pointed out that the concentration of Na in leaves could not be used as a selection criterion at higher NaCl concentrations.

The literature reports that low Na and high K uptake and a high K/Na ratio show a positive relationship with salt tolerance (Gorham, 1990; Ashraf et al., 1997; Sherif et al., 1998). The results of our study, in terms of enhancing the success in salt tolerance, indicate that more attention should be given firstly to high K uptake and then to high K/Na ratios. However, because of differences in K and Na uptake and their distribution in the shoots and roots, and possible differences in the tolerance mechanism in different genotypes (Datta et al., 1995), it is difficult to say that these criteria can always be applied to all genotypes. However, in this study, significant and positive interactions were found between the salt tolerance index and K concentration, K/Na ratio, germination and dry weight, whereas the salt tolerance index had negative but insignificant interactions with Na in the roots and shoots.

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