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Full Length Research Paper

Genotypic variation in the response of tomato to salinity

Ahmet Turhan[1]*, Vedat Şeniz[2] and Hayrettin Kuşçu[1]

[1]Department of Industrial Plants Cultivation and Evaluation, Mustafakemalpasa Vocational School, University of Uludag, 16500 Bursa, Turkey.
[2]Department of Horticultural Science, Faculty of Agriculture, University of Uludag, 16059 Gorukle, Bursa, Turkey.

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In order to determine the predictive screening parameters that can be applied at early development stages of tomato plants, 18 tomato cultivars were grown in nutrient solution with 12 dS m^{-1} NaCl. The research was conducted in a completely randomized design with tree replications. The relationships among the salinity and root, stem, leaf accumulation, K^+/Na^+ and Ca^{2+}/Na^+ ratios and root-stem-leaf dry weights were investigated. At the end of treatment, regarding studied parameters morphologic and physiologic changes were determined depending on increasing NaCl concentrations. With increasing concentrations, it was determined that all growth parameters were decreased. However, this decrease in salt tolerant cultivars was restricted as compared to salt sensitive cultivars. It was also determined that by increasing NaCl applications, the amount of Na^+ was increased and, the amount of Ca^{2+} and K^+ ions were decreased in salt tolerant cultivars same with growth parameters. Thus, it was concluded that, more K^+ or Ca^{2+} absorbing plant with high K^+/Na^+ and Ca^{2+}/Na^+ rations were more salt tolerant. At end of the study, it was determined that dry weights and K/Na^+- Ca^{2+}/Na^+ ratios were very effective on the salt tolerance. Considering the cultivars, H-2710 was characterized as more salt tolerant under saline conditions.

Key words: Tomato, genotypes, salt stress tolerance, salt treatment.

INTRODUCTION

High concentrations of salt in soils account for large decreases in the yield of a wide variety of crops all over the world (Tester and Davenport, 2003). The amount of land affected by secondary salinity (salinity caused by human activity) is steadily increasing. Recent estimates prove that over 70 million ha of agricultural land is affected: 20% of irrigated land, and about 2% of dry land (FAO, 2005). Currently, a third of all irrigated lands in the world are affected to a greater or lesser degree by salinity, and the salinity problem continues to increase (Munns, 2005). Tomato is one of the most important horticultural crops in the world, and tomato plant growth was shown to be moderately sensitive or moderately tolerant to salinity depending on cultivar or growth stage (Santa-Cruz et al., 2002; Fernandez-Garcia et al., 2004 and Estan et al., 2005).

*Corresponding author. E-mail: turhan@uludag.edu.tr. Tel: +90 224 613 31 02 (61556). Fax: +90 224 613 21 14.

Salt stress affects many aspects of plant metabolism and as a result, growth and yields are reduced. Excess salt in the soil solution may adversely affect plant growth either through osmotic inhibition of water uptake by roots or specific ion effects. Salinity impacts plants in two main ways: osmotic stress and ion toxicity (Munns, 2005). Osmotic stress is caused by ions (mainly Na^+ and Cl^-) in the soil solution decreasing the availability of water to roots. Ion toxicity occurs when plant roots take up Na^+ and/or Cl^- ions and these ions are accumulated to detrimental levels in leaves. Ion imbalances and nutrient deficiency, particularly for K^+ nutrition, can also occur (Tejera et al., 2006).

Salinity stress results in a clear stunting of plant growth, which results in a considerable decrease in fresh and dry weights of leaves, stems and roots. Increasing salinity is also accompanied by significant reductions in shoot weight, plant height and root length (Parida and Das, 2005; Hajer et al., 2006). Exposure of plants to salt stress usually begins in the roots. This leads to changes in growth, morphology and physiology of the root that will in

turn change water and ion uptake and the production of signals that sends information to shoot. The whole plant is then affected when roots are growing in a salty medium. Tomato cultivars varied significantly in their response to different salinity levels. Increasing NaCl concentrations in nutrient solution adversely affect tomato shoots and roots, plant height, K^+ concentration, and K^+/Na^+ ratio (Al-Karaki, 2000). Yield reductions induced by salinity may be due to both the osmotic stress that results from relatively high solute concentrations in the root growing medium, and specific toxicity due to the accumulation of high concentrations of Na and Cl in the plant, which provokes a wide variety of physiological and biochemical alterations that inhibit plant growth and production (Maggio et al., 2004; Munns, 2005).

Salinity was shown to increase the uptake of Na or decrease the uptake of Ca and K (Neel et al., 2002). In general, Ca^{2+} and K^+ concentrations decrease with salinisation but not in all genotypes; in Edkawy, concentrations remain unchanged and in *L. pennellii* they increase slightly (Bolarin et al., 1995). Maintenance or increase of Ca^{2+} concentration could induce maintenance of K^+ since the presence of Ca^{2+} seems to be necessary for K-Na selectivity and for the maintenance of an appropriate K^+ concentration in plant cells. Low values of K^+/Na^+ and Ca^{2+}/Na^+ ratios in roots appear as better indicators of salt stress than the Na concentration alone (Rengel, 1992; Rubio et al., 2003). Ability of plant genotypes to maintain higher levels of K^+ and Ca^{2+} and low levels of Na^+ within tissue is one of the key mechanisms contributing to expression of high salt tolerance. In most cases, salt tolerant genotypes are capable of maintaining higher K^+/Na^+ ratios in tissues (Mansour, 2003; Zeng et al., 2003). Genotypes for high tolerance to salt stress the K^+/Na^+ and Ca^{2+}/Na^+ ratios and tissue Na^+ concentrations are, therefore, wisely used parameters for different crop species (Ashraf and Harris, 2004; Santa-Cruz et al., 2002; Munns and James, 2003).

For the use of practical genetic variation in breeding programs, large number of genotypes should be considered in screening tolerance to NaCl. In this study, 18 tomato genotypes have been screened for NaCl tolerance based on Ca^{2+}/Na^+ and K^+/Na^+. The results implicate that H-2710 was the most tolerant genotype due to the high level of K^+/Na^+ and Ca^{+2}/Na^+ concentrations in root,-stem,-and leafs by-12 dS m^{-1}.

MATERIALS AND METHODS

As plant material, 18 tomato (*Lycopersicon esculentum*) cultivars, as listed in Table 1, were used. The investigations were conducted under greenhouse conditions at the Department of Horticulture and Soil Sciences at Uludag University. Seeds were initially germinated in organic enriched peat with a vermiculite cover to facilitate aerations, in open plastic trays. The average glasshouse temperatures were 15 and 25°C at night and day, respectively, whereas the relative humidity was maintained at 70%. 35 days after emergence, old seedlings (3-4 true leaves) were transplanted into a 14 cm plastic pots filled with peat:perlite (1:1 on volume basis) homogenous mixture. The transplanted plants were transferred to the glasshouse. Seedlings of the tomato were grown in peat/perlite medium for 40 days. When the plants had developed 4-5 true leaves, applications of Hoagland solution containing 0 (control) and 12 dS m^{-1} NaCl were started via drip irrigation. The composition of the nutrient solution was as follows: in g 1000 l-1; 38.32 mono-ammonium phosphate (MAP), 202.00 potassium nitrate (KNO_3), 393.24 calcium nitrate [$Ca(NO_3)_2.4H_2O$], 164.00 magnesium sulphate ($MgSO_4.7H_2O$), 11.65 iron chelate (Fe-EDTA), 0.95 boric acid (H_3BO_3), 0.11 zinc sulphate ($ZnSO_4.7H_2O$), 0.0095 ammonium molybdate [$(NH_4)_6\ Mo_7O_{24}.4H_2O$], 0.77 manganese sulphate ($MnSO_4.H_2O$), and 0.04 copper sulphate ($CuSO_4.5H_2O$). Plants were irrigated with their respective solution 1-2 times per day. It was attempted to keep the quantity of drainage water at 30% of the amount of nutrient solution applied. The electrical conductivity in the medium was 2.0 ± 0.3 (control), 12 ± 0.6 dS m^{-1}, respectively. The salt level was gradually increased over 1 week to avoid osmotic shock.

Plants were grown in a controlled greenhouse with day and night average temperature of 28.7°C, average relative humidity of 70%, and average photoperiod of 16 h. The experiment was set up using a randomized block design and replicated 3 times. There was 1 plant in each pot (1 l), with 4 pots in each replicate. Experiments were conducted for two consecutive spring seasons (2003 and 2004).

At the end of the experiments, plants were separated into leaf, stem and root parts. The parts first washed with tap water to remove growing media and nutrient solutions, and then dried at 70°C for 48 h. Finally dry weights were measured. Total Ca^{2+}, K^+ and Na^+ concentrations were also measured on nitric-perchloric acid digests of root, stem, and leaf tissue by Eppendorf Elex model Fleymfotometry. Ca^{2+}/Na^+ and K^+/Na^+ ratios were calculated for plants growing under controlled and 12 dS m^{-1} NaCl applied environments.

Data were analyzed using MSTAT-C (version 2.1, Michigan State University, 1991) and Minitab 14.0 software. Analysis of variance (ANOVA) was conducted and significance of differences among treatment was tested using the least significant difference (LSD). Differences were declared significant at $P<0.05$ probability levels by the F test. The F-protected LSD calculated at 0.05 probability levels according to Steel and Torrie (1980).

RESULTS

Growth response

Analysis of variance revealed significant differences among dry weights of different tomato cultivars. Dry weight was strongly affected by salinity treatments. Increased salt concentration significantly reduced dry weights of root, stem and leaf in all tomato cultivars at 12 dS m^{-1}. Compared to the control treatment, the decrease in dry weight (g) varied from 66 to 88% in root, 72 to 89% in stem, and 61 to 92% in leaf. On average, root, stem and leaf dry matter production of H-2710 was least affected by NaCl treatment than others cultivars. The decrease in dry matter production was 66, 72 and 61% in root, stem and leaf, respectively. On the other hand, Falcon, Alta and Primopack, SUN-6200 was most affected by 12 dS m^{-1} NaCl. The reduction in root dry weight was 88% in Falcon, reductions in stem dry weight were 89% in Alta and Primopack. As for the leaf dry weight, reduction was 90 and 92% in Primopack and Sun-6200.

Table 1. Root, stem, leaf dry weight in tomato cultivars under saline condition (average of 2003 and 2004 years).

Cultivar	Root dry weight (g)			Stem dry weight (g)			Leaf dry weight (g)		
	Control	NaCl (12 dS m^{-1})	Reduction (%)	Control	NaCl (12 dS m^{-1})	Reduction (%)	Control	NaCl (12 dS m^{-1})	Reduction (%)
Star	4.38 c-f	0.57 e-g	87 ab	2.59 d-f	0.49 a-f	81 cd	10.18 b	2.60 ab	74 ef
Falcon	4.82 a-d	0.58 e-g	88 a	3.59 c	0.54 a-e	85 a-c	7.99 cd	1.22 c-e	84 bc
Shaste	5.43 a	1.03 bc	77 cd	2.42 e-h	0.57 a-d	76 de	8.11 cd	2.52 ab	69 f
H-2274	4.67 b-e	0.81 c-e	75 d	2.02 h	0.52 b-f	75 e	7.30 de	1.89 a-c	74 ef
Challenger	3.75 f-h	0.65 d-g	83 a-c	2.84 de	0.39 e-g	87 ab	6.58 e	0.86 c-e	87 ab
Menemen	2.63 j	0.67 d-g	75 d	2.32 f-h	0.37 fg	84 a-c	8.26 cd	1.69 b-e	79 c-e
Alta	4.62 b-e	0.68 d-g	85 ab	4.04 ab	0.43 c-g	89 a	9.73 b	1.66 b-e	83 b-d
Rio Grande	3.25 h-j	0.87 b-d	81 a-d	2.79 de	0.39 e-g	85 a-c	7.44 c-e	1.50 b-e	79 c-e
XPH	4.09 e-g	0.81 c-e	80 b-d	3.93 a-c	0.48 b-f	88 a-c	9.68 b	1.53 b-e	84 bc
UG-812	3.11 ij	0.44 g	86 ab	4.20 a	0.70 a	83 bc	10.58 b	1.82 a-d	83 b-d
H-2710	4.91 a-c	1.70 a	66 e	2.12 gh	0.58 a-c	72 e	7.35 de	2.83 a	61 g
Red Gold	4.39 c-e	1.11 b	80 b-d	2.78 de	0.43 c-g	85 a-c	9.74 b	1.95 a-c	80 cd
Design	4.97 a-c	0.85 b-d	83 a-c	4.26 a	0.54 a-e	87 ab	6.67 e	1.13 c-e	83 b-d
H-9885	5.12 ab	0.95 b-c	81 a-d	3.69 bc	0.64 ab	83 bc	7.68 cd	1.38 c-e	82 b-d
AG-2219	4.21 d-f	0.80 c-f	81 a-d	2.90 d	0.41 d-g	86 a-c	11.64 a	2.57 ab	78 de
SC2121	3.23 h-j	0.54 fg	83 a-c	2.52 d-g	0.57 a-d	77 de	8.4 c	1.59 b-e	81 cd
SUN 6200	3.08 ij	0.53 g	83 a-c	2.72 d-f	0.30 g	88 ab	7.93 cd	0.66 e	92 a
Primopack	3.53 g-ı	0.63 d-g	82 a-d	3.71 bc	0.41 d-g	89 a	7.84 cd	0.78 de	90 a
LSD (%5)	0.64	0.26	7.34	0.42	0.17	5.81	0.97	1.11	5.01

Values with the same letter are not significantly different.

H-2710 root, stem and leaf dry weights were 1.70, 0.58 and 2.83, respectively. Falcon root dry weight was 0.58, Alta and Primopack stem dry weights were 0.43 and 0.41. Finally, Primopack and SUN-6200 leaf dry weights were 0.78 and 0.66 (Table 1).

Physiological response

Root, stem and leaf K^+/Na^+ and Ca^{2+}/Na^+ ratios of 18 cultivars grown in Salt stress at 12 dS m^{-1} against the control treatment are given at Tables 2 and 3. The cultivars showed large variation in tolerance to 12 dS m^{-1} NaCl treatment based on root, stem, leaf, K^+/Na^+ and Ca^{2+}/Na^+ ratios and reductions (%) compared to the control treatment. Among the 18 cultivars screened, H-2710 was found to be the most salt tolerant cultivar followed by H-2274 and Shaste. All these cultivars were less affected by salt treatment. The cultivar XPH, UG-812, H-9885, SUN 6200, Primopack were the most sensitive cultivars to salinity, followed by Challenger, Menemen, Alta, Red Gold, Rio Grande. The remaining cultivars were placed in medium salt tolerant cultivars.

There was large variation in root K^+/Na^+ and Ca^{2+}/Na^+ ratios among 18 cultivars under 12 dS m^{-1} NaCl treatment. Root $K^{+/}Na^+$ and Ca^{2+}/Na^+ ratios of the tolerant cultivars was less affected by NaCl treatment than the sensitive cultivars. For instance, tolerant H-2274, H-2710 and Shaste K^+/Na^+, Ca^{2+}/Na^+ ratios were reduced by 86-91, 88-88 and 89-89%, respectively. Within sensitive cultivars, the reduction in root K/Na was 97% in Challenger. The measured reduction in root Ca^{2+}/Na^+ ratios was 98% for both Menemen and Alta. The sensitive and tolerant cultivars were similar in root Ca^+ and K^+ concentrations at NaCl treatment as a consequence of greater increase in Na^+ and decreases in K^+-Ca^{2+} concentration by NaCl treatment. Sensitive cultivars exhibited much smaller K^+/Na^+ and Ca^{2+}/Na^+ ratios compared to the tolerant cultivars. The most tolerant cultivars H-2274, H-2710 and Shaste had K^+/Na^+ - Ca^{2+}/Na^+ ratios 0.52 - 0.71, 0.80 - 0.88 and 0.64 - 0.71, respectively. However, among sensitive cultivars Challenger had a K^+/Na^+ ratio of 0.25, Menemen and Alta had $Ca2^+/Na^+$ ratios of 0.29 and 0.24, respectively (Tables 2 and 3).

Decreases in stem K^+/Na^+ and Ca^{2+}/Na^+ ratios caused by salt stress were similar to the decreases in root K^+/Na^+ and Ca^{2+}/Na^+ ratios. One of the tolerant cultivars H-2710 stem K^+/Na^+ and Ca^{2+}/Na^+ ratios were reduced by 85 and 87%, respectively, while in sensitive cultivars the reductions in stem K^+/Na^+ (in XPH, UG-812) and Ca^{2+}/Na^+ (in Red Gold and H-9885) ratio were 97%. The most tolerant cultivar H-2710 had K^+/Na^+ - Ca^{2+}/Na^+ ratios of 0.94 and 0.92, respectively. K^+/Na^+ and Ca^{2+}/Na^+ ratios were significantly reduced in sensitive cultivars, and cultivars XPH, UG-812, Red Gold, H-9885 had K^+/Na^+

Table 2. Root, stem, leaf K^+/Na^+ ratios of the cultivars grown saline condition (average of 2003 and 2004 years).

Cultivar	Root K^+/Na^+			Stem K^+/Na^+			Leaf K^+/Na^+		
	Control	NaCl (12 dS m^{-1})	Reduction (%)	Control	NaCl (12 dS m^{-1})	Reduction (%)	Control	NaCl (12 dS m^{-1})	Reduction (%)
Star	5.38 de	0.48 c	90 ef	8.47 a	0.55 d	94 b-d	6.56 a-c	0.85 d	87 b
Falcon	3.14 gh	0.25 e	92 de	5.57 f-h	0.38 e-g	93 cd	5.47 fg	0.38 f-i	93 a
Shaste	6.00 b-d	0.64 b	89 fg	6.69 b-d	0.95 a	86 f	6.25 a-e	1.19 b	80 de
H-2274	3.64 f-h	0.52 c	86 h	7.11 b	0.84 b	89 e	7.01 a	1.24 ab	82 cd
Challenger	7.24 a	0.25 e	97 a	7.31 b	0.33 f-h	96 ab	7.00 ab	0.50 e	93 a
Menemen	3.40 gh	0.19 e-h	95 a-c	7.21 b	0.40 ef	95 a-c	5.84 c-f	0.44 e-g	93 a
Alta	3.74 f-h	0.23 e-g	94 b-d	6.05 d-f	0.28 h-j	95 a-c	5.39 fg	0.44 e-g	92 a
Rio Grande	4.70 ef	0.24 ef	95 a-c	6.80 bc	0.32 gh	96 ab	6.74 ab	0.32 h-j	95 a
XPH	2.92 h	0.16 g-i	94 b-d	5.72 e-g	0.22 ij	97 a	5.30 fg	0.26 j	95 a
UG-812	4.12 fg	0.16 g-i	96 ab	5.66 fg	0.22 ij	97 a	4.88 g	0.34 g-j	94 a
H-2710	6.79 ab	0.80 a	88 gh	6.33 c-e	0.94 a	85 f	6.24 b-e	1.35 a	78 e
Red Gold	5.90 b-d	0.22 e-g	96 ab	5.01 h	0.29 hi	95 a-c	4.72 g	0.40 e-h	92 a
Design	5.66 c-e	0.22 e-g	96 ab	5.97 ef	0.45 e	92 d	6.43 a-d	0.40 e-h	94 a
H-9885	2.99 h	0.17 f-i	95 a-c	5.62 f-h	0.22 ij	96 ab	5.24 fg	0.27 ij	95 a
AG-2219	5.78 b-e	0.40 d	93 c-e	6.74 bc	0.33 f-h	96 ab	5.66 ef	0.48 ef	92 a
SC2121	6.59 a-c	0.33 d	95 a-c	6.06 d-f	0.70 c	89 e	6.76 ab	0.99 c	85 bc
SUN 6200	2.68 h	0.11 i	96 ab	5.86 e-g	0.21 j	96 ab	5.70 d-f	0.28 ij	95 a
Primopack	2.99 h	0.12 hi	96 ab	5.29 gh	0.21 j	96 ab	5.14 fg	0.26 j	95 a
LSD (%5)	1.13	0.07	2.31	0.64	0.08	2.33	0.77	0.12	3.13

Values with the same letter are not significantly different.

and Ca^{2+}/Na^+ ratios of 0.22 - 0.23, 0.22 - 0.28, 0.29 - 0.23, 0.22 - 0.22, respectively (Tables 2 and 3).

In leaf, the K^+/Na^+ and Ca^{2+}/Na^+ ratios were significantly influenced by salinity treatment. Increasing salinity level decreased the ratios of K^+/Na^+ and Ca^{2+}/Na^+, and there were considerable differences between salinity treatment and treatment under no salinity. For example, H-2710 leaf K^+/Na^+ and Ca^{2+}/Na^+ ratios were reduced by 78 and 84%, respectively. On the other hand, Rio Grande, XPH, H-9885, Sun-6200, Primopack leaf K^+/Na^+ ratios reduced up to 95% under no salinity, and the reduction was up to 96% in Primopack and Sun-6200 leaf Ca^{2+}/Na^+ ratio (Tables 2 and 3).

Maximum K^+/Na^+ and Ca^{2+}/Na^+ ratios were observed with the tolerant cultivar H-2710 at 12 dS m^{-1} NaCl treatment (K^+/Na^+ = 1.35, Ca^{2+}/Na^+ = 1.19). Leaf K^+/Na^+ and Ca^{2+}/Na^+ ratios at 12 dS m^{-1} for sensitive cultivars Rio Grande, XPH, H-9885, Sun-6200, and Primopack were: 0.32, 0.26, 0.27, 0.28, 0.26 and 0.73, 0.32, 0.34, 0.42, 0.32, respectively.

DISCUSSION

In tomato plants subjected to salinity, Na^+ and Ca^{+2}, K^+ accumulation in root, stem, leaf are determined by genotype. Plants growing under saline conditions accumulate more Na, resulting in ionic imbalance (specific ion deficiency symptoms in plants). Decreased K^+ and Ca^{2+} uptake apparently depresses growth at higher Na^+ concentrations (Cuartero and Fernandez-Munoz, 1999; Sairam et al., 2002). The K^+ deficiency of salinized plants was inversely correlated to the increased accumulation of Na^+, indicating the existence of competition effects between Na^+ and K^+ ions which most likely share the same transport system at the root surface (Rus et al., 2001). The reduced calcium uptake in response to salt stress has been reported for tomato and other species and it has been associated to a decreased transpiration rate rather than competition effects with Na^+. Within certain limits, additional Ca^{2+} may ameliorate plant response to salinity (Maggio et al., 2006). When absorbed and accumulated at large amount in plant, Na^+ becomes highly toxic at different physiological levels. Physiological impairments caused by Na^+ toxicity include disruption of K^+ and Ca^{2+} nutrition, development of water stress and induction of oxidative cell damage (Aktas et al., 2006).

The control of Na accumulations and high K^+/Na^+ ratios may enhance salt tolerance and the K^+/Na^+ ratio has been used as a nutritional indicator by a number of authors to select salt tolerant in tomato crops (Asch et al., 2000; Al-Karaki, 2000; Dasgan et al., 2002; Juan et al., 2005). Santa-Cruz et al. (2002) have observed that the K^+/Na^+ ratio in leaves of tomato plants submitted to salt stress is a better overall indicator of the ability of the plant to select and use K^+ under Na^+ salinisation, the extent that the maintenance of highest K^+/Na^+ ratio is important for tomato salt tolerance. In the present study, the result

Table 3. Root, stem, leaf Ca^{+2}/Na^{+} ratios of the cultivars grown saline condition (average of 2003 and 2004 years).

Cultivar	Root K^+/Na^+			Stem K^+/Na^+			Leaf K^+/Na^+		
	Control	NaCl (12 dS m^{-1})	Reduction (%)	Control	NaCl (12 dS m^{-1})	Reduction (%)	Control	NaCl (12 dS m^{-1})	Reduction (%)
Star	9.67 ab	0.39 c	96 b	7.41 a-c	0.55 cd	93 de	10.26 bc	1.26 a	88 fg
Falcon	6.11 e	0.22 de	97 ab	6.95 c-e	0.28 f	96 ab	8.53 f	0.67 c	93 b-d
Shaste	7.16 d	0.71 b	89 d	7.31 a-d	0.80 b	89 g	8.20 f-h	1.30 a	84 h
H-2274	7.33 d	0.71 b	91 c	8.14 ab	0.74 b	91 f	9.08 d-f	1.21 a	87 g
Challenger	7.28 d	0.25 de	97 ab	7.17 a-d	0.31 f	96 ab	7.53 g-i	0.61 c	92 c-e
Menemen	8.83 bc	0.29 d	98 a	8.25 a	0.73 b	91 f	9.07 d-f	0.74 c	92 c-e
Alta	9.75 ab	0.24 de	98 a	5.85 e-g	0.30 f	95 bc	8.60 ef	0.68 c	92 c-e
Rio Grande	7.03 de	0.22 de	97 ab	6.89 c-e	0.54 cd	92 ef	10.52 b	0.73 c	93 b-d
XPH	6.44 de	0.17 e	97 ab	5.59 f-h	0.23 f	96 ab	5.45 k	0.32 d	94 a-c
UG-812	7.18 d	0.23 de	96 b	5.52 f-h	0.28 f	95 bc	7.04 ij	0.36 d	95 ab
H-2710	7.09 de	0.88 a	88 d	6.91 c-e	0.92 a	87 h	7.20 ij	1.19 a	84 h
Red Gold	8.85 bc	0.26 de	97 ab	6.60 c-f	0.23 f	97 a	8.24 fg	0.65 c	92 c-e
Design	10.07 a	0.25 de	97 ab	6.28 d-g	0.43 e	93 de	11.52 a	0.98 b	91 de
H-9885	6.77 de	0.20 de	97 ab	6.60 c-f	0.22 f	97 a	6.38 jk	0.34 d	95 ab
AG-2219	7.01 de	0.23 de	97 ab	7.09 b-d	0.51 de	93 de	10.01 b-d	0.66 c	93 b-d
SC2121	8.49 c	0.65 b	92 c	6.93 c-e	0.61 c	92 ef	9.53 c-e	0.99 b	90 ef
SUN 6200	6.93 de	0.20 de	97 ab	4.51 h	0.27 f	94 cd	8.65 ef	0.42 d	96 a
Primopack	6.81 de	0.20 de	97 ab	5.42 gh	0.22 f	96 ab	7.26 h-j	0.32 d	96 a
LSD (%5)	1.02	0.10	1.49	1.11	0.096	1.72	0.96	0.14	2.34

Values with the same letter are not significantly different.

for the K^+/Na^+ ratio was similar to those indicated by other authors. Highest root, stem, leaf K^+/Na^+ ratio values were found in the H-2710 genotype, which were less affected by salinity.

In our experiments with tomato cultivars, plant growth under 12 dS m^{-1} saline conditions accumulated more of Na^+, decreased Ca^{2+} uptake, reducing Ca^{2+}/Na^+ ratios in root, shoot and leaf. Conversely, some cultivars were more reluctant to lesser Ca^{2+}/Na^+ ratios thus, were less affected by high salt concentrations. For instance, for H-2710 highest Ca^{2+}/Na^+ ratios were measured at 12 dS m^{-1}. H-2710 could maintain growth at high salt concentrations; thus, it is clear that H-2710 is the most salt tolerant cultivar. Studies indicate that an increase in concentrations of Ca^{2+} and K^+ in plant under salt stress could improve the harmful effects of salinity on growth and yield (Grattan and Grieve, 1999; Sivritepe et al., 2003; Kaya et al.; 2003). Reduction of K^+ and Ca^{2+} ions in plant tissues at high level of NaCl treatments is also a very known fact for other plant varieties; tomato, melon and eggplant (Savvas and Lenz, 2000), spinach (Wilson et al., 2000), pepper (Aktas et al., 2006), squash plant (Yıldırım et al., 2006). Ca^{2+} ions controls salt tolerance in different ways: First of all, they maintain Na accumulation in tissues (Rengel, 1992), and prevents Na ions entering into the cell (Maathius et al., 1996). Preservation of or increase in Ca concentration could induce maintenance of K^+, because the presence of Ca^{2+} seems to be necessary for K-Na selectivity and for the maintenance of an appropriate amount of K^+ concentration in plant cells. Rengel (1992), Neel et al. (2002) and Rubio et al. (2003) also state low values of Na^+/K^+ and Na^+/Ca^{2+} ratios in roots being a better indicators of salt stress than the Na concentration alone. Plant ability to maintain higher levels of K^+ and Ca^{2+} and low levels of Na^+ is one of the keystones to express high salt tolerance. Overall, salt-tolerant cultivars are capable of maintaining higher K^+/Na^+ ratios in tissues (Mansour, 2003; Zeng et al.; 2003), and the K^+/Na^+ and Ca^{2+}/Na^+ ratios and tissue Na concentration are, therefore, wisely used parameters to determine high salt tolerance of different crops (Ashraf and Harris, 2004; Santa-Cruz et al., 2002; Dasgan et al., 2002; Munns and James, 2003).

The result of the study demonstrates that the K^+/Na^+ and Ca^{2+}/Na^+ ratios are better overall indicators of plant's ability to resist NaCl stress. Besides, selection and use of K^+ and Ca^{2+} under Na^+ salinisation, as well as the maintenance of high K^+/Na^+ and Ca^{2+}/Na^+ ratios is also essential for salt tolerance. In this study, highest ratio values were found in the H-2710 cultivar, which was less affected by salinity.

The result indicated that the root, stem and leaf dry weights are decreased in saline conditions. Similar outcomes were obtained earlier by several researchers as well (Maggio et al., 2006; Mohammad et al., 1998; Tıpırdamaz and Karakullukçu, 1993, Hajer et al., 2006).

Al-Rwahy (1989) the reduction of the dry weights due to increased salinity may be a result of a combination of osmotic and specific ion effects of Cl and Na. Excessive accumulation of Na ions in root, stem and leaf, leads to plant depression by preventing K^+ and Ca^{2+} accumulation, which also triggers the reduction in dry weights at high NaCl concentrations (Caines and Shannon, 1999). On the other hand, some researchers have reported no such relation between dry weights and Na^+ concentrations (Al-Karaki, 2000; Dasgan et al., 2002).

In spite of the negative effect of salt on root, stem and leaf dry weights in tomato, some varieties appear to be less affected by salinity treatment. This argument is also similar to the results obtained by Cruz and Cuartero (1990). Dry weight differences under salt treatment is a widely used evaluation criteria; as with Agong et al. (1997), morphological characterization is used in studying salt tolerance is in many crops.

Finally, in this study salinity stress results in a clear stunting of plant growth, which results in a considerable decrease in dry weights (root, stem and leaf). Increasing salinity is companied also by significant reductions in root, stem and leaf Ca/Na and K/Na ratios.

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REFERENCES

Agong GS, Schittenhelm S, Friedt W (1997). Assessment of tolerance to salt stress in Kenya tomato germplasm. Kluwer Academic Publisher Netherlands. 95: 57-66.

Aktas H, Abak K, Cakmak I (2006). Genotypic variation in the response of pepper to salinity. Sci. Hortic. 110: 260-266.

Al–Karaki GN (2000). Growth water use efficiency and sodium and potassium acquisition by tomato cultivars grown under salt stress. J. Plant Nutr. 23: 1-8.

Al–Rwahy SA (1989). Nitrogen uptake, growth rate and yield of tomatoes under saline condition. PhD. Dissertation, University of Arizona, Tuscon, p. 118.

Asch F, Dingkuhn M, Dorffling K, Miezan K (2000). Leaf K/Na ratio predicts salinity–induced yield loss in irrigated rice. Euphytica, 113: 109-118.

Ashraf M, Harris PJC (2004). Potential indicators of salinity tolerance in plants. Plant Sci. 166: 3-16.

Bolarin MC, Santa-Cruz A, Cayuela E, Perez-Alfocea F (1995). Short–term solute changes in leaves and roots of cultivated and wild tomato seedling under salinity. J. Plant Physiol. 147: 463-468.

Caines AM, Shanon C (1999). Interactive effect of Ca and NaCl salinity on the growth of two tomato genotypes differing in Ca use efficiency. Plant Physiol. Biochem. 37(7/8): 569-576.

Cruz V, Cuartero J (1990). Effect of salinity at several developmental stages of six genotypes of tomato (Lycopersicon spp.) In: Cuartero J, Gomez-Guillamon M, Fernandez-Munoz R. Edition, Malaga, Spain, pp. 81-86.

Cuartero J, Fernandez–Munoz R (1999). Tomato and salinity. Scientia Hortic. 78: 83-125.

Dasgan HY, Aktas H, Abak K, Cakmak I (2002). Determination of screening techniques to salt tolerance in tomatoes and investigation of genotype responses. Plant Sci. 163: 695-703.

Estan MT, Martinez–Rodriguez MM, Perez–Alfocea F, Flowers TJ, Bolarin MC (2005). Grafting raises the salt tolerance of tomato through limiting the transport of sodium and chloride to the shoot. J. Exp. Bot., 56: 703-712.

FAO (2005). Global network on integrated soil management for sustainable use of salt-affected soils. FAO Land and Plant Nutrition Management Services, Rome Italy. http://www.fao.org/ag/agl/agll/spush.

Fernandez-Garcia N, Martinez V, Cerdá A, Carvajal M (2004). Fruit quality of grafted tomato plants grown under saline conditions. J. Hortic. Sci. Biotech. 79: 995-1001.

Grattan SR, Grieve CM (1999). Salinity–mineral nutrient relations in horticultural crops. Sci. Hortic., 78: 127-157.

Hajer AS, Malibari AA, Al Zahrani HS, Almaghrabi OA (2006). Responses of three tomato cultivars to sea water salinity. Effect of salinity on the seedling growth. Afr. J. Biotechnol. 5: 855-861.

Juan M, Rosa M, Rivero LR, Juan MR (2005). Evaluation of some nutritional and biochemical indicators in selecting salt-resistant tomato cultivars. Environ. Exp. Bot. 54: 193-201.

Kaya C, Higgs D, Ince F, Amador BM, Cakir A, Sakar E (2003). Ameliorative effects of potassium phosphate on salt-stressed pepper and cucumber. J. Plant Nutr. 26: 807-820.

Maathuis FJM, Verlin D, Smith FA, Sanders D, Fernandez JA, Walker NA (1996). The physiological relevance of Na–coupled K transport. Plant Physol. 112: 1609-1616.

Maggio A, De Pascale S, Angelino G, Ruggiero C, Barbieri G (2004). Physiological response of tomato to saline irrigation in long term salinized soils. Eur. J. Agron. 21: 149-159.

Maggio A, Raimondi G, Martino A, Pascale S (2006). Salt response in tomato beyond the salinity tolerance threshold. Environmental and experimental botany. Department of Agricultural Engineering and Agronomy of the University of Naples Federico II, Italy. 11: 131-141.

Mansour MMF (2003). Transport proteins and salt tolerance in plants. Plant Sci. 164: 891-900.

Mohammad M, Shibii R, Ajouni M, Nimri L (1998). Tomato root and shoot responses to salt stress under different levels of phosphorus nutrition. J. Plant Nutr. 21: 1667-1680.

Munns R, James RA (2003). Secreening methods for salinity tolerance: a case study with tetraptoid wheat. Plant Soil, 253: 201-218.

Munns R (2005). Genes and salt tolerance: bringing them together. New Phytologist, 167: 645-663.

Neel JPS, Alloush G, Belesky ADP, Clapham WM (2002). Influence of rhizosphere ionic strength on mineral composition, dry matter yield and nutritive vale of forage chicory. J. Agron. Crop Sci. 188: 398-407.

Parida AK, Das AB (2005). Salt tolerance and salinity effects on plants: a review. Exotoxicol Environ. 60: 324-349.

Rengel Z (1992). The role of calcium in salt toxicity. Plant and Cell Environ. 15: 625-632.

Rubio F, Flores P, Navarro JM, Martinez V (2003). Effects of Ca^{+2} K^+ and cGMP on Na^+ uptake in pepper plants. Plant Sci. 165: 1043-1049.

Rus AM, Estañ MT, Gisbert C, Garcia-Sogo B, Serrano R, Caro M, Moreno V, Bolarin MC (2001). Expressing the yeast HAL1 gene in tomato increases fruit yield and enhances K^+/Na^+ selectivity under salt stress. Plant Cell Environ. 24: 875-880.

Sairam RK, Rao KV, Srivastava GC (2002). Differential response of wheat genotypes to long term salinity stress in relation to oxidative stress, antioxidant activity and osmolyte concentration. Plant Sci. 163: 1037-1046.

Santa-Cruz A, Martinez-Rodriguez M, Perez-Alfocea F, Romero-Aranda R, Bolarin MC (2002). The roostock effect on the tomato salinity response depends on the shoot genotype. Plant Sci. 162: 825-831.

Savvas D, Lenz F (2000). Effect of NaCl or nutrient-induced salinity on growth, yield and composition of eggplant grown in rockwooll. Sci. Hort. 84: 37-47.

Sivritepe N, Sivritepe HO, Eris A (2003). The effects of NaCl priming on salt tolerance in melon seedlings grown under saline conditions. Sci. Hortic. 97: 229-237.

Steel RGD, Torrie JH (1980). Principles and procedures of statistics. A biometrical approach. McGraw-Hill, New York, pp. 186-187.

Tejera NA, Soussi M, Lluch C (2006). Physiological and nutritional indicators of tolerance to salinity in chickpea plants growing under symbiotic conditions. Environ. Exp. Bot. 58: 17-24.
Tester M, Davenport R (2003). Na^+ tolerance and Na^+ transport in higher plants. Ann. Bot. 91: 503-507.
Tıpırdamaz R, Karakullukçu S (1993). Prolin ve glisinbetain'in tuzlu koşullarda kültüre alınmış domates embriyolarının gelişmesi ve bazı içsel madde değişimleri üzerine etkileri. Doğa-Tr. J. Bot. 17: 54-64 (in Turkish).
Yıldırım E, Taylor AG, Spittler TD (2006). Ameliorative effects of biological treatments on growth of squash plants under salt stress. Sci. Hortic. 111: 1-6.
Wilson C, Lesch MS, Grieve CM (2000). Growth stage modulates salinity tolerance of New Zealand spinach and red orach. Ann. Bot. 85: 501-509.
Zeng L, Poss J, Wilson C, Draz ASE, Grieve CM (2003). Evaluation of salt tolerance in rice genotypes by physiological characters. Euphytica, 129: 281-292.