J. Agr. Sci. Tech. (2014) Vol. 16: 851-862

Characterization of Comparative Response of Fifteen Tomato (*Lycopersicon esculentum* Mill.) Genotypes to NaCl Stress

M. Amjad[1,2*], J. Akhtar[2], M. Anwar-ul-Haq[2], R. Ahmad[3], and M. Zaid[2]

ABSTRACT

A solution culture experiment was conducted to evaluate the salinity tolerance of 15 tomato genotypes in Hoagland's nutrient solution with three levels of NaCl (0, 75, and 150 mM). The experiment was conducted in completely randomized design with three replicates. After 30 days of imposition of salt stress, gas exchange parameters including transpiration rate, stomatal conductance, CO_2 assimilation rate, and intercellular CO_2 concentration were recorded and the harvested plants were characterized for growth (shoot/ longest root lengths and fresh/dry weights) and ionic characteristics (Na^+, K^+ and K^+/Na^+ ratio) parameters. All growth and gas exchange parameters decreased with increasing NaCl concentrations. However, this decrease was less in salt-tolerant genotypes as compared to salt-sensitive genotypes. It was also observed that with the increasing NaCl concentration in the rooting medium, the amount of Na^+ in the plant tissues increased while the amount of K^+ ion decreased. Thus, it was concluded that the plants with more K^+ absorbing ability, with high K^+/Na^+ ratio, and higher growth were more salt-tolerant. Also, the results showed that fresh and dry weights, gas exchange characteristics, and K^+/Na^+ ratio were very effective in determining salt tolerance of tomato. Considering the genotypes, Indent-1 and Nagina were characterized as salt tolerant and the Red Ball and Peto-86 as salt sensitive under saline conditions.

Keywords: Salinity tolerance, K^+/Na^+, Photosynthesis, Growth

INTRODUCTION

Salinity is among the major environmental constraints that not only affects the growth, productivity, and performance of crop plants, but also limits the use of land for agricultural purposes. According to estimates, soil salinity affects about 7% of the total land and 20% of the irrigated land of the world (Yamaguchi and Blumwald, 2005). In Pakistan, about 6.67 M ha is salt affected, which is about one third of the total cultivated area (Khan, 1998).

The main impediments of the growing media salinity on growth and yield of plants are osmotic effect, specific ion toxicity, nutritional imbalance, and, above all, production of reactive oxygen species (ROS), which ultimately bring out disturbances in photosynthesis and physiology of the plants (Telesiñski *et al*., 2008; Zhao *et al*., 2007). These impediments of salinity severely affect chlorophyll fluorescence and the growth of stem, leaves, and roots as well as fresh and dry weights (Hajer *et al*., 2006).

Previous methods used for assessing salt tolerance of plants were based on yield response and were not very effective because of excess amount of time they take and expensiveness (Gama *et al*., 2009). Certain physiological characters can be used to assess the salt tolerance of

[1] Department of Plant and Environmental Sciences, University of Copenhagen, Denmark.
[*] Corresponding author E-mail: amjad_ses@yahoo.com
[2] Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad-38040, Pakistan.
[3] Department of Agronomy, University of Agriculture Faisalabad-38040, Pakistan.

plants; for example, photosynthesis rate can provide an assessment of salt stress tolerance (Gama *et al*., 2009); and chlorophyll fluorescence is the quantitative indicative of the photosynthesis (Zhao *et al*., 2007; Ehsanzadeh *et al*., 2009).

Potassium is an essential plant nutrient that takes part in important physiological processes like photosynthesis, assimilative transport, and activation of enzymes, especially under stress conditions such as drought (Liebersbach *et al*., 2004) and salinity (Qi and Spalding, 2004). Considerable differences exist among different species and genotypes such as wheat (Damon and Rengel, 2007), potato (Trehan *et al*., 2005; Arvin and Donnelly, 2008), canola (Damon *et al*., 2007), rice (Yang *et al*., 2004), cotton (Zhang *et al*., 2007), tomato (Ezin *et al*., 2010). Therefore, knowledge of K uptake and accumulation for biomass production under saline stress conditions can be used to assess the salt-tolerance of different genotypes and understand the mechanism of salinity tolerance.

Tomato is moderately salt-tolerant and is commonly cultivated in salinized areas (Lu *et al*., 2010). Use of salt-tolerant species/ varieties is one of the most feasible and effective options to tackle salinity (Yilmaz, 2004). The plant species or varieties may differ significantly for salt tolerance due to their genetic makeup (Kausar *et al*., 2012).

In Pakistan, area under tomato cultivation is 49992 ha with a total production of 476826 tons (FAO, 2010). According to a survey on kitchen crops, per capita consumption of tomato in Pakistan has increased from 1.88 kg per head in 2007 to 2.89 kg per head in 2010. Therefore, the current study was conducted with the objective to assess the effect of different salinity levels on growth, physiology, and phenotype of tomato genotypes that may lead to screening salt-tolerant and salt-sensitive tomato genotypes.

MATERIALS AND METHODS

Plant Material and Growth Conditions

Twelve tomato (*Lycopersicon esculentum* Mill.) genotypes (Indent-1, Indent-2, Roma, 1211, 127, Pakit, Nagina, VCT-1, Riogrande, Estra-229, LA-3847, LA-0716) and three varieties (Peto-86, Red Ball, Titano) were obtained from National Agricultural Research Council (NARC), Islamabad, and Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, and used in this study.

The experiment was carried out in a wire house during spring 2010 (February, March) at University of Agriculture, Faisalabad (Latitude = 31°- 26' N, Longitude = 73°- 06' E, Altitude = 184.4 m), with average minimum and maximum temperatures of 9.5-30.4 °C and relative humidity of 57.5-62.7%. Healthy seeds of each genotype/ variety were surface sterilized with 1% sodium hypochlorite solution and sown in polythene lined iron trays having two-inches layer of acid washed quartz sand, on 12th February. After germination, seedlings were irrigated with ½ strength Hoagland's nutrient solution (Hoagland and Arnon, 1950). At two-leaf stage, uniform seedlings were randomly transferred to foam plugged holes (2 cm diameter) in polystyrene sheet suspended over ½ strength Hoagland's nutrient solution. One week after transplanting, three levels of NaCl salinity (0, 75, and 150 mM) were maintained by stepwise increment of lab grade NaCl i.e. one third of the total salt for three consecutive days (25 and 50 mM, respectively). Aeration was given with air pumps for 8 hours a day, pH was maintained daily at 6.0-6.5, and nutrient solution was changed every 10 days.

Measured Parameters

Growth Parameters

To assess the effect of NaCl on plant growth, after 30 days of salt stress, three seedlings of each genotype were collected,

root and shoot were separated, and used for measurement of shoot and the longest root lengths and fresh weights. Shoot and root dry weights were measured after drying them in oven at 65 ± 5 °C in hot air oven (Model DHG-9053A, R & M Marketing, Sussex, UK) till constant weight.

Photosynthetic Parameters

After 30 days of salt stress, photosynthetic parameters including transpiration rates, stomatal conductance, CO_2 assimilation rate, and intercellular CO_2 concentration were recorded by using portable Infra-red gas analyzer (LCA4 - ADC Bioscientific).

Leaf sap analysis

Two or 3 youngest fully expanded leaves of tomato genotypes were detached after 30 days of salt treatment, rinsed quickly in distilled water, blotted dry with tissue paper, and stored in separate Eppendorf tubes at freezing temperature for leaf sap extraction to determine Na^+ and K^+. Frozen leaf samples were thawed and crushed using a stainless steel rod with tapered end. The sap was collected in Eppendorf tubes by Gilson pipette and centrifuged at 6500 x g for 10 minutes (Gorham, 1984). The leaf sap was diluted as required by adding distilled water and Na^+ and K^+ were determined using flame photometer (Sherwood Flame photometer, Model-410; Sherwood Scientific, Ltd, Cambridge UK) with the help of standard solutions using reagent grade salts of NaCl and KCl.

Statistical Analysis

The experiment was conducted using a completely randomized design with three replicates. Each treatment was analyzed and a standard error (SE) was calculated; data were expressed as mean ± SE replicates. Results were examined by analysis of variance with "Statistix 8.1" (www.statistix.com).

RESULTS

Plant Growth Parameters

The growth of the fifteen genotypes as measured in terms of shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, and root dry weight decreased significantly ($P < 0.05$) with increasing concentration of NaCl.

After 30 days of imposition of salt stress, Indent-1 and Nagina were the least affected while Peto-86 and Red Ball were the most affected genotypes in terms of decrease in growth of shoot and root (Table 1, 2, 3).

Gas Exchange Parameters

With the increasing concentration of NaCl (75 and 150 mM) in the nutrient solution, all the gas exchange characteristics i.e. CO_2 assimilation rate, stomatal conductance, transpiration rate, and intercellular CO_2 concentration decreased significantly ($P < 0.05$) in all the genotypes (Table 4, 5). Results revealed that Indent-1 and Nagina maintained comparatively highest values of these gas exchange attributes among all the genotypes, and Peto-86 and Red Ball maintained the lowest, except the transpiration rate, which was lowest in Red Ball and LA-3847 at 150 mM NaCl.

Leaf Sap K^+ and Na^+ Content and K^+/Na^+ Ratio

With increasing NaCl concentration in the nutrient solution, an opposite trend was found between leaf Na^+ and K^+ concentration. Leaf Na^+ concentration increased, whereas K^+ concentration decreased significantly ($P < 0.05$) in all the fifteen tomato genotypes (Table 5). As a result of this opposite trend between Na^+ and

Table 1. Effect of three levels of NaCl (Control, 75 and 150 mM) on shoot length and the longest root length of fifteen tomato genotypes/varieties after 30 days of imposition of stress.

Genotype /Variety	Shoot Length (cm)			The Longest Root Length (cm)		
	Control	75 mM NaCl	150 mM NaCl	Control	75 mM NaCl	150 mM NaCl
Peto-86	37.0 ±1.2	27.4±1.5(74)	19.1±0.5(52)	37.7±2.4	26.6±1.2(70)	19.7± 0.4(52)
Red Ball	34.7 ±2.2	26.7±0.8 (77)	18.0±0.5(52)	36.0±1.3	29.2±0.6(81)	19.2 ± 0.6(53)
1211	46.0 ±3.7	34.7±0.5(75)	22.9±1.7(50)	56.2±1.9	37.0±1.1(66)	19.5± 1.9(35)
Roma	39.3 ± 2.8	27.4±1.1(70)	19.8±0.6(50)	39.6±1.1	29.2±0.8 (74)	20.3± 0.6(51)
127	46.3 ±1.4	33.4±0.9(72)	24.0±0.7(53)	49.6±2.3	33.7±1.3(68)	23.5± 0.8(47)
Indent-1	65.7 ±1.3	56.4±1.1(87)	46.4±1.1(71)	79.6±1.3	65.9±1.9(83)	45.1± 2.0(57)
Indent-2	45.3 ±1.7	32.5±1.2(72)	26.3±0.8(58)	57.7±2.0	42.1±0.7(73)	35.6± 0.7(62)
Pakit	45.7 ±2.1	33.6±0.8(74)	22.9±0.7(50)	51.4±1.8	35.9±0.9(70)	22.8± 0.7(44)
Nagina	58.4 ±1.8	47.7±0.7(82)	40.6±0.7(70)	64.8±0.9	52.8±1.6(81)	37.5± 0.7(59)
VCT-1	47.0 ±1.2	35.1±1.3(75)	24.6±0.8(52)	51.8±2.1	36.3±0.8(70)	23.6± 1.9(46)
Riogrande	46.6 ±1.4	34.3±0.9(74)	23.1±0.5(50)	55.1±1.1	36.6±1.6 (66)	22.2± 0.7(40)
Titano	48.7 ±2.3	34.0±0.7(70)	21.5±1.7(44)	46.6±1.3	34.1±0.9(73)	22.8± 0.9(49)
Estra-229	51.0±1.2	40.0±1.2(78)	27.2±0.5(53)	54.0±1.5	38.3±1.0(71)	22.6± 0.6(42)
LA-3847	45.3 ±1.3	32.2±0.7(71)	21.8±0.7(48)	43.3±1.4	28.9±1.1(67)	23.0± 0.7(53)
LA-0716	48.6 ±1.2	39.0±0.8(80)	28.4±0.7(58)	54.0±1.7	40.1±0.9(74)	22.4± 0.8(42)

Values are means of three replicates± SE, Values in the parentheses are percent of control .

Table 2: Effect of three levels of NaCl (Control, 75 and 150 mM) on shoot fresh weight and root fresh weight of fifteen tomato genotypes/varieties after 30 days of imposition of stress

Genotype /Variety	Shoot Fresh Weight (g)			Root Fresh Weight (g)		
	Control	75 mM NaCl	150 mM NaCl	Control	75 mM NaCl	150 mM NaCl
Peto-86	46.0±2.6	33.6±1.1(73)	22.1±1.1(48)	3.7 ± 0.2	2.3 ± 0.1 (62)	1.6 ± 0.1 (43)
Red Ball	43.4±0.7	33.6±1.5(69)	25.5±0.7(59)	3.5 ± 0.1	2.3 ± 0.1 (66)	1.4 ± 0.1 (44)
1211	64.7±1.8	42.6±1.1(66)	34.4±1.7(53)	5.2 ± 0.3	2.9 ± 0.1 (56)	1.9 ± 0.2 (36)
Roma	45.5±2.2	33.6±1.5(74)	26.4±1.1(58)	3.7 ± 0.2	2.3 ± 0.1 (62)	1.7 ± 0.1 (46)
127	66.4±2.2	54.9±3.7(83)	32.3±2.2(49)	5.0 ± 0.1	3.4 ± 0.1 (68)	2.6 ± 0.1(52)
Indent-1	91.9±2.6	76.6±1.6(83)	59.9±1.2(65)	7.4 ± 0.2	5.3 ± 0.3 (72)	3.8 ± 0.2 (51)
Indent-2	57.0±1.7	38.1±1.8(67)	24.9±1.5(44)	5.9 ± 0.2	4.0 ± 0.1 (68)	2.4 ± 0.1 (41)
Pakit	59.1±1.5	41.3±1.1(70)	28.1±1.5(48)	4.7 ± 0.1	2.9 ± 0.1 (62)	1.8 ± 0.1 (38)
Nagina	74.5±1.5	63.0±1.5(85)	49.8±1.5(67)	6.5± 0.1	4.9 ± 0.1 (75)	3.6 ± 0.1 (55)
VCT-1	59.6±4.2	41.7±1.9(70)	27.3±1.3(46)	4.8 ± 0.3	2.9 ± 0.1 (61)	1.8 ± 0.1 (38)
Riogrande	78.7±2.2	42.1±1.8(54)	32.8±1.1(42)	5.2 ± 0.2	2.9 ± 0.1 (56)	1.9 ± 0.1 (36)
Titano	66.4±2.2	45.5±2.5(68)	30.4±1.5(46)	5.3 ± 0.2	3.8 ± 0.1 (72)	2.0 ± 0.1 (38)
Estra-229	73.6±2.2	53.4±1.5(73)	37.9±1.1(52)	4.6 ± 0.1	3.2 ± 0.1 (70)	2.1 ± 0.1 (46)
LA-3847	49.8±1.9	34.6±1.5(70)	25.8±1.5(52)	4.0 ± 0.2	2.6 ± 0.1 (65)	1.7 ± 0.1 (42)
LA-0716	53.6±2.6	40.3±1.8(75)	26.3±1.8(49)	4.3 ± 0.2	2.7 ± 0.1 (63)	1.8 ± 0.1 (42)

Values are means of three replicates± SE, Values in the parentheses are percent of control

Table 3. Effect of three levels of NaCl (Control, 75 and 150 mM) on shoot dry weight and root dry weight of fifteen tomato genotypes/varieties after 30 days of imposition of stress.

Genotype /Variety	Shoot Dry Weight (g)			Root Dry Weight (g)		
	Control	75 mM NaCl	150 mM NaCl	Control	75 mM NaCl	150 mM NaCl
Peto-86	2.6±0.2	1.9±0.1(73)	1.3±0.1(50)	0.36±0.03	0.26±0.02(72)	0.21±0.02(58)
Red Ball	2.6±0.3	1.9±0.2(73)	1.1±0.1(42)	0.34±0.01	0.26±0.02(76)	0.20±0.01(59)
1211	3.6±0.2	2.4±0.1(67)	1.7± 0.3(47)	0.51±0.03	0.33±0.02(65)	0.25±0.03(49)
Roma	2.4±0.1	1.9±0.2(79)	1.3± 0.1(54)	0.36±0.04	0.26±0.02(72)	0.17±0.02(47)
127	3.7±0.2	2.1±0.1(57)	1.5±0.1(40)	0.45±0.02	0.33±0.03(73)	0.27±0.02(60)
Indent-1	5.1±0.3	4.3±0.4(84)	3.0± 0.2(59)	0.72±0.04	0.60±0.05(83)	0.48±0.04(67)
Indent-2	3.2±0.2	2.6±0.1(81)	1.6± 0.1(50)	0.52±0.03	0.43±0.02(83)	0.29±0.02(56)
Pakit	3.3±0.2	2.3±0.2(70)	1.4±0.1(42)	0.46±0.02	0.32±0.03(70)	0.22±0.02(48)
Nagina	4.2±0.1	3.3±0.1(79)	2.4±0.2(57)	0.58±0.02	0.53±0.09(91)	0.39±0.02(67)
VCT-1	3.0±0.3	2.1±0.2(70)	1.5±0.1(50)	0.42±0.04	0.30±0.02(71)	0.23±0.02(55)
Riogrande	3.4±0.2	2.2±0.2(65)	1.6±0.3(47)	0.51±0.04	0.33±0.03(65)	0.26±0.02(51)
Titano	3.3±0.4	2.3±0.1(70)	1.4±0.2(42)	0.47±0.06	0.33±0.02(70)	0.22±0.03(47)
Estra-229	2.9±0.2	1.8±0.1(62)	1.4±0.1 (48)	0.49±0.03	0.43±0.02(88)	0.30±0.02(61)
LA-3847	2.8±0.2	2.2±0.1(79)	1.3±0.1 (46)	0.39±0.03	0.31±0.02(80)	0.21±0.02(54)
LA-0716	3.1±0.2	2.2±0.2(71)	1.6±0.1 (52)	0.52 ±0.03	0.40±0.03(77)	0.32±0.02(62)

Values are means of three replicates± SD, Values in the parentheses are percent of control.

Table 4: Effect of three levels of NaCl (Control, 75 and 150 mM) on CO_2 assimilation rate and transpiration rate of fifteen tomato genotypes/varieties after 30 days of imposition of stress

Genotype /Variety	CO_2 Assimilation Rate (μmol m^{-2} s^{-1})			Transpiration Rate (mmol m^{-2} s^{-1})		
	Control	75 mM NaCl	150 mM NaCl	Control	75 mM NaCl	150 mM NaCl
Peto-86	2.70± 0.06	1.72± 0.03	1.08± 0.03	1.98± 0.09	1.36± 0.04	1.05± 0.04
Red Ball	2.55± 0.07	1.58± 0.04	1.04± 0.03	2.00± 0.03	1.42± 0.05	0.96± 0.03
1211	3.80± 0.05	2.42± 0.03	1.32± 0.10	2.81± 0.06	1.85± 0.04	1.21± 0.13
Roma	2.68± 0.02	1.80± 0.04	1.11± 0.02	1.89± 0.08	1.32± 0.05	1.11± 0.04
127	3.90± 0.06	2.86±0.04	1.09± 0.04	2.89± 0.08	2.15± 0.05	1.54± 0.12
Indent-1	5.41± 0.07	4.37± 0.09	3.23± 0.07	3.96± 0.09	3.24± 0.13	2.62± 0.14
Indent-2	3.35± 0.04	2.19± 0.17	1.49± 0.04	2.48± 0.06	1.73± 0.08	1.24± 0.05
Pakit	3.48± 0.04	2.43± 0.05	1.25± 0.04	2.57± 0.05	1.80± 0.06	1.22± 0.05
Nagina	4.38± 0.04	3.62± 0.03	2.78± 0.04	3.24± 0.05	2.57± 0.04	1.97± 0.05
VCT-1	3.50± 0.07	2.45± 0.05	1.22± 0.05	2.33± 0.14	1.43± 0.05	1.10± 0.13
Riogrande	3.63± 0.06	2.48± 0.05	1.18± 0.03	2.43± 0.08	1.83± 0.07	1.07± 0.04
Titano	3.74± 0.11	2.54± 0.04	1.24± 0.10	2.59± 0.08	1.61± 0.06	1.07± 0.05
Estra-229	3.51± 0.06	2.39± 0.04	1.31± 0.03	2.20± 0.08	1.48± 0.05	1.09± 0.04
LA-3847	2.93± 0.05	1.92± 0.04	1.14± 0.04	2.17± 0.07	1.72± 0.05	1.03± 0.05
LA-0716	2.84± 0.06	1.76± 0.05	1.09± 0.04	2.69± 0.09	1.92± 0.06	1.46± 0.06

Values are means of three replicates± SE.

K^+ with the increasing NaCl concentration, K^+/Na^+ also decreased significantly in these genotypes (Table 7). However, Indent-1 and Nagina maintained a fairly low concentration of Na^+ and higher concentration of K^+ as compared to the other genotypes at higher levels of NaCl in the nutrient solution e.g. 75 and 150 mM, whereas Peto-86 and Red Ball showed the maximum concentration of Na^+ and minimum concentration of K^+ at 150 mM NaCl.

DISCUSSION

There was overall reduction in tomato plant growth with the elevated concentration of NaCl as compared to non-saline conditions. There are two reasons for the inhibition of plant growth: firstly, because of reduced water availability to the plants due to excess of NaCl in the nutrient solution; and secondly, due to specific ion toxicity (Munns *et al*., 2006). This was in accordance with the previous findings by Kumar *et al*. (2005) who ascribed the reduced plant growth to decreased water absorption due to osmotic effects, deficiency of nutrients as a consequence of the ionic imbalance, and decrease in many metabolic activities. Hence, different plant species have evolved different strategies to tackle with these deleterious effects of excess salts in the rooting medium (Munns *et al*., 2006). Results of this study are consistent with previous ones; plant height (root and shoot length) is reduced under saline conditions (Tantawy *et al*., 2009; Yokas *et al*., 2008).

The shoot and root fresh and dry weights were decreased due to the exposure of increasing concentration of NaCl (75 and 150 mM). Similar results were also found earlier by Oztekin and Tuzel (2011) in other tomato cultivars. Saline stress changed the morphology, growth, and physiology of the roots that altered the water and ion uptake, consequently, the whole plant growth was affected. A similar trend was also documented by other authors (Li *et al*., 2004; Akhtar *et al*., 2010). Finally, saline conditions resulted in a clear stunting of plant growth and, as a result, the shoot and root length as well as the fresh and dry weights were considerably decreased in all the genotypes. In our study, shoot and root

Table 5. Effect of three levels of NaCl (Control, 75 and 150 mM) on stomatal conductance and intercellular CO_2 concentration of fifteen tomato genotypes/varieties after 30 days of imposition of stress.

Genotype /Variety	Stomatal Conductance(mmol m^{-2} s^{-1})			Intercellular CO_2 Concantration (µmol mol^{-1})		
	Control	75 mM NaCl	150 mM NaCl	Control	75 mM NaCl	150 mM NaCl
Peto-86	0.24± 0.02	0.18±0.01	0.11± 0.01	82.4±7.1	60.8±3.5	56.4±4.2
Red Ball	0.25± 0.02	0.18±0.01	0.10± 0.01	83.2±6.3	62.8±4.8	47.3±4.2
1211	0.35± 0.02	0.23±0.02	0.14± 0.01	117.0±5.8	87.0±3.7	57.0±4.7
Roma	0.23 ± 0.01	0.17±0.01	0.12± 0.01	98.5±4.3	66.7±4.8	54.6±5.1
127	0.35± 0.02	0.29±0.03	0.22± 0.01	133.2±7.1	104.0±4.6	81.0±3.4
Indent-1	0.49± 0.02	0.41±0.01	0.32± 0.01	166.3±8.3	138.6±3.9	117.3±5.7
Indent-2	0.30± 0.03	0.21±0.02	0.15± 0.01	103.2±5.3	85.6±6.9	57.4 ±3.5
Pakit	0.32± 0.01	0.22±0.01	0.16± 0.01	107.0±4.8	74.7±5.8	60.1±4.2
Nagina	0.40± 0.01	0.34± 0.01	0.27± 0.02	144.8±4.8	114.0±6.1	106.5±7.1
VCT-1	0.29± 0.02	0.20±0.02	0.13± 0.01	97.0±8.3	72.4±3.9	53.1±3.3
Riogrande	0.32± 0.02	0.22±0.01	0.15± 0.01	114.7±7.1	87.2±4.5	67.1±4.4
Titano	0.32± 0.04	0.21±0.01	0.13± 0.01	131.0 ±6.7	107.8±3.4	75.5± 4.7
Estra-229	0.29± 0.02	0.20±0.02	0.13 ± 0.02	120.1 ±6.9	99.3 ±4.2	71.7±3.9
LA-3847	0.27± 0.03	0.21±0.01	0.14± 0.01	90.1 ±5.7	71.6±5.1	57.3±4.8
LA-0716	0.32± 0.01	0.25±0.01	0.15± 0.01	120.1 ±6.8	93.2 ±6.4	76.5 ±3.9

Values are means of three replicates± SD

Table 6: Effect of three levels of NaCl (Control, 75 and 150 mM) on leaf sap Na^+ and K^+ concentration of fifteen tomato genotypes/varieties after 30 days of imposition of stress

Genotype/Variety	Leaf Sap Na^+ (mol m^{-3})			Leaf Sap K^+ (mol m^{-3})		
	Control	75 mM NaCl	150 mM NaCl	Control	75 mM NaCl	150 mM NaCl
Peto-86	35.5± 0.4	78.9± 2.5	148.7± 3.7	226.4 ±2.2	175.4 ±4.6	126.5±2.6
Red Ball	28.7± 0.2	64.9± 2.5	141.7± 2.1	239.8 ±8.0	170.3±3.4	124.1±3.4
1211	33.3± 0.3	69.1± 2.5	136.2± 5.3	237.4 ±5.6	188.4±3.4	120.8±6.4
Roma	31.6± 0.1	96.0± 2.6	128.6± 2.4	237.5 ±6.8	165.9±4.6	126.0±3.4
127	39.7± 0.3	79.5± 2.6	133.1± 2.2	244.5 ±5.1	157.0±9.9	110.6±4.5
Indent-1	25.6± 0.3	58.8± 2.5	102.5± 4.6	285.6 ±5.3	214.5 ±8.3	179.3±5.3
Indent-2	34.0 ± 0.3	70.1± 2.7	134.3 ± 3.4	246.3± 6.7	155.1±4.4	114.0±3.7
Pakit	34.8± 0.2	85.0± 2.8	135.8± 2.9	222.6± 4.6	137.2±5.6	117.3±4.4
Nagina	25.0± 0.4	63.9± 2.6	117.3± 2.6	256.2 ±3.5	192.6±2.5	140.5± 3.3
VCT-1	46.7± 0.4	77.0± 2.8	134.8± 3.6	185.1± 8.6	137.6 ±4.6	112.0±5.5
Riogrande	30.4± 0.3	81.7± 2.8	137.7± 2.6	244.0 ±6.8	139.8 ±5.9	112.9±3.4
Titano	33.0± 2.6	72.9± 2.1	139.4± 5.4	199.7 ±8.0	116.6± 5.6	88.2±5.6
Estra-229	40.4± 0.3	80.2± 1.6	140.5± 3.6	231.5± 6.8	126.6± 4.4	97.1± 3.4
LA-3847	39.9± 0.3	82.8± 1.8	133.8± 4.1	218.8±5.9	136.4± 4.4	111.5±4.4
LA-0716	39.0± 0.3	86.4± 2.1	139.4± 3.2	226.3 ±6.7	142.0± 5.1	113.1±4.6

Values are means of three replicates± SE

Table 7. Effect of three levels of NaCl (Control, 75 and 150 mM) on K^+/Na^+ ratio of fifteen tomato genotypes/varieties after 30 days of imposition of stress

Genotype /Variety	Control	75 mM NaCl	150 mM NaCl
	6.40±0.26	2.24±0.19	0.85±0.03
Peto-86	8.35±0.51	2.63±0.07	0.88±0.03
Red Ball	7.19±0.53	2.73±0.04	0.89±0.05
1211	7.56±0.65	1.73±0.10	0.98±0.02
Roma	6.16±0.15	1.97±0.05	0.83±0.03
127	11.33±0.95	3.65±0.15	1.75±0.07
Indent-1	7.32±0.69	2.27±0.28	0.85±0.02
Indent-2	6.46±0.54	1.61±0.03	0.86±0.02
Pakit	10.33±0.60	2.40±0.14	1.20±0.04
Nagina	4.00±0.35	1.79±0.03	0.83±0.01
VCT-1	8.07±0.74	1.72±0.11	0.81±0.03
Riogrande	6.10±0.47	1.60±0.05	0.63±0.02
Titano	5.76±0.35	1.58±0.06	0.69±0.01
Estra-229	5.51±0.27	1.65±0.08	0.83±0.02
LA-3847	5.85±0.42	1.65±0.09	0.81±0.02

Values are means of three replicates± SE

length, fresh and dry weights of Indent-1 and Nagina genotypes were generally least reduced and Peto-86 and Red Ball were most reduced as compared with other genotypes/varieties. This indicated that they were more tolerant to the effect of an increase in salinity and could better cope with reduced water availability.

It is evident from the previous findings that under salt stress, stomata closed due to decreased water availability and uptake by the roots (Christina *et al*., 2010). Due to the stomatal closure, stomatal conductance, and internal CO_2 concentration were decreased, consequently, plant's net photosynthetic rate and transpiration rate were also decreased,

thereby diminishing the growth of plants (Figure 1). This disruption in stomatal regulation under saline conditions was attributed to the decreased level of K in plants. This could be because K had a significant role as osmoticum in vacuole to maintain high tissue water content under stress condition (Marschner, 1995). There are many reports that depict the importance of K in regulating the photosynthesis and maintaining the water balance of plants (Stepien and Kłbus, 2006; Athar and Ashraf, 2005). In our present work, NaCl stress led to the significant decrease in the gas exchange characteristics in all the fifteen genotypes. Since growth of plants was directly correlated to these gas exchange parameters, the genotypes Indent-1 and Nagina maintained higher values of these attributes and produced more biomass as compared to the other varieties/genotypes, whereas Peto-86 and Red Ball produced less biomass because of lower values of these attributes.

The results depicted that leaf Na^+ content were increased and leaf K^+ content decreased with the increasing concentration NaCl in the nutrient solution. Under saline conditions, more accumulation of Na^+ resulted in ionic imbalance and, as a consequence, plant uptake of K^+ decreased, as apparent by the depressed growth at higher NaCl concentrations (Sairam *et al.*, 2002; Dadkhah, 2011). The deficiency of K^+ under salinized conditions was inversely correlated to the increased accumulation of Na^+, indicating the effects of competition between Na^+ and K^+ ions, which might be due to the fact that these two ions share the same transport system at the root surface (Rus *et al.*, 2001). When large amounts of Na^+ are absorbed and accumulated by plants, it becomes highly toxic at different levels of physiology. Physiologically, Na^+ toxicity causes disruption of K^+ nutrition, induction of water stress, and oxidative cell damage

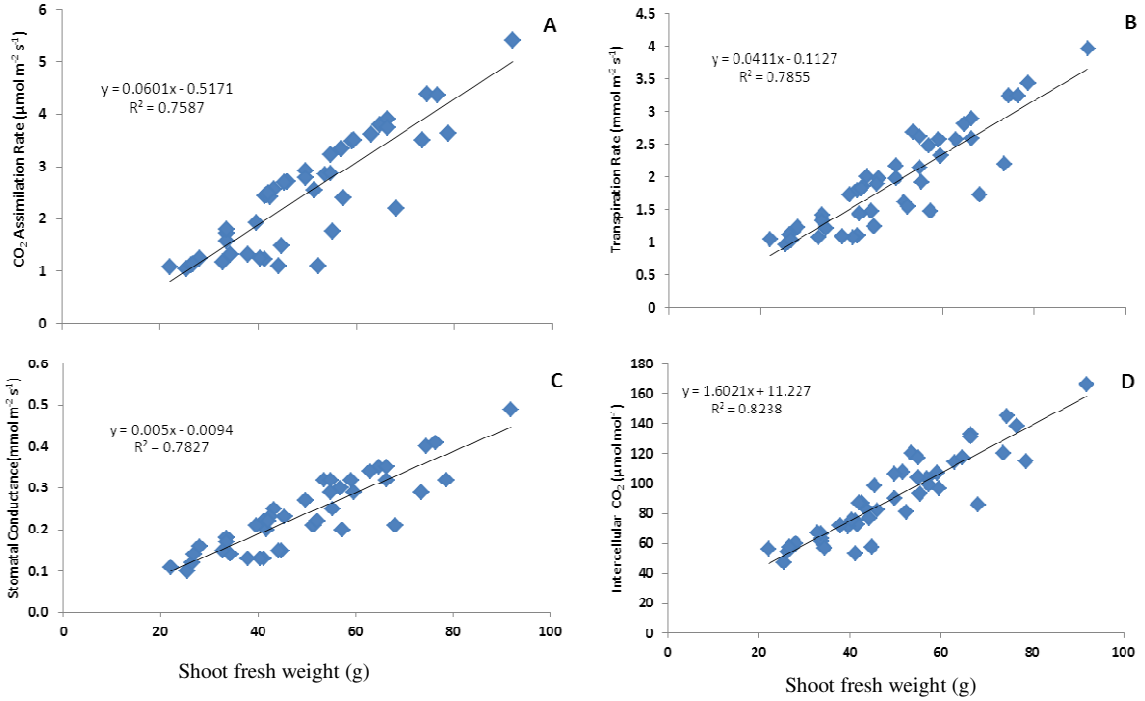

Figure 1. Relationship between CO_2 assimilation rate (A), transpiration rate (B), stomatal conductance (C), and intercellular CO_2 concentration (D) and shoot fresh weight of fifteen tomato genotypes/varieties after 30 days of imposition of NaCl stress.

(Aktas *et al*., 2006). The restricted absorption and accumulation of Na^+ and maintenance of high K^+/Na^+ ratios may enhance salt tolerance. Thus, the K^+/Na^+ ratio has served as a nutritional indicator to select salt tolerant genotypes/ varieties in tomato crop (Juan *et al*., 2005; Dasgan *et al*., 2002). In tomato leaves, maintaining high K+/Na+ ratio is a good indicator to select salt tolerant genotypes (Santa-Cruz *et al*., 2002). In the present study, the result for the K^+/Na^+ ratio was comparable to those documented earlier by other authors. Highest leaf K^+/Na^+ ratio values were observed in the Indent-1 and Nagina, which were less affected by salinity, and the lowest was recorded for Peto-86 and Red Ball, which were affected more by salinity.

Based on the results, it is concluded that salinity severely affected tomato plant physiology and, thus, resulted in decreased plant growth. Among all the genotypes, Indent-1 and Nagina were characterized as salt-tolerant and Peto-86 and Red Ball as salt-sensitive under saline conditions. The results obtained in this study are important for the farmers of the region and useful for researchers in breeding tomato for salt tolerance.

ACKNOWLEDGEMENT

We are very much thankful to the Higher Education Commission of Pakistan (HEC) for financial support for this project.

REFERENCES

1. Akhtar, J., Saqib, Z. A., Sarfraz, M., Saleem, I. and Haq, M. A. 2010. Evaluating Salt Tolerant Cotton Genotypes at Different Levels of NaCl Stress in Solution and Soil Culture. *Pak J Bot*., **42(4)**: 2857-2866.
2. Aktas, H., Abak, K. and Cakmak, I. 2006. Genotypic Variation in the Response of Pepper to Salinity. *Sci. Horticul.*, **110**: 260-266.
3. Arvin, M. J. and Donnelly, D. J. 2008. Screening Potato Cultivars and Wild Species to Abiotic Stresses Using an Electrolyte Leakage Bioassay. *J. Agric. Sci. Technol*., **10**: 33-42.
4. Athar, H. and Ashraf, M. 2005. Photosynthesis under Drought Stress. In: Pessarakli, M. (Ed.), Handbook of Photosynthesis, Second Ed. CRC Press, New York, pp. 795–810.
5. Christina, E., Reynolds, H., Anita, L., Jan M., Nicole S., Anita, Z. and Urs, F. 2010. Interactions between Temperature, Drought and Stomatal Opening in Legumes. *Environ. Exp. Bot.*, **68**: 37–43.
6. Dadkhah, A. 2011. Effect of Salinity on Growth and Leaf Photosynthesis of Two Sugar Beet (*beta vulgaris* L.) Cultivars. *J. Agr. Sci. Tech*., **13**: 1001-1012.
7. Damon, P. M, and Rengel, Z. 2007. Wheat Genotypes Differ in Potassium Efficiency under Glasshouse and Field Conditions. *Aust. J. Agric. Res.,* **58**: 816–825
8. Damon, P. M., Osborne, L. D. and Rengel, Z. 2007. Canola Genotypes Differ in Potassium Efficiency during Vegetative Growth. *Euphytica*, **156**: 387–397.
9. Dasgan, H. Y., Aktas, H., Abak, K. and Cakmak, I. 2002. Determination of Screening Techniques to Salt Tolerance in Tomatoes and Investigation of Genotype Responses. *Plant Science*, **163**: 695-703.
10. Ehsanzadeh, P., Nekoonam, M. S., Azhar, J. N., Pourhadian, H. and Shaydaee, S. 2009. Growth, Chlorophyll, and Cation Concentration of Tetraploid Wheat on a Solution High in Sodium Chloride Salt: Hulled Versus Free-Threshing Genotypes. *J. Plant Nutrit.*, **32**: 58–70.
11. Ezin, V., Robert, D. P. and Adam A. 2010. Physiological and Agronomical Criteria for Screening Tomato Genotypes for Tolerance to Salinity. *EJEAFChe,* **9 (10)**: 1641-1656.
12. FAO, 2010. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor
13. Gama, P. B., Tanaka, S., Eneji, K., Eltayeb, A. E. and Siddig, K. E. 2009. Salt-induced Stress Effect on Biomass, Photosynthetic Rate and Reactive Oxygen Species-Scavenging Enzyme Accumulation in Common Bean. *J. Plant Nutrit.*, **32**: 837-854.
14. Gorham, J. 1984. Salt Tolerance in the Triticae: K^+/Na^+ Discrimination in Some Potential Wheat Grasses and Their

Amphiploids with Wheat. *J Exper Bot,* **45**: 441-447.
15. Hajer, A. S., Malibari, A., Al-Zahrani, H. S. and Almaghrabi, O. A. 2006. Responses of Three Tomato Cultivars to Seawater Salinity 1- Effect of Salinity on the Seedling Growth. *Afric. J. Biotech.*, **5**: 855-861.
16. Hoagland, D. R. and Arnon, D. I. 1950. The Water Culture Method for Growing Plant Without Soil. *California Agri. Exp. Station Circl*. **345**:39.
17. Juan, M., Rosa, M., Rivero, L. R. and Juan, M. R. 2005. Evaluation of Some Nutritional and Biochemical Indicators in Selecting Salt-resistant Tomato Cultivars. *Environ. Exp. Bot.*, **54**: 193-201.
18. Kausar, R., M. Arshad, A. Shahzad and S. Komatsu. 2013. Proteomics Analysis of Sensitive and Tolerant Barley Genotypes under Drought Stress. *Amino Acids,* **44**: 345-359.
19. Khan, G. S. 1998. Soil Salinity-sodicity Status in Pakistan. *Soil Surv. Pak. Lahore.* Pp. 59.
20. Kumar, R., Goyal, V. and Kuhad, M. S. 2005. Influence of Frtility-salinity Interactions on Growth, Water Status and Yield of Indian Mustard (*Brassica juncea*). *Ind. J. Plant Phys.*, **10**: 139-144.
21. Li, Y. L., Marcelis, L. F. M., Stanghellini, C. 2004. Plant Water Relations as Affected by Osmotic Potential of the Nutrient Solution and Potential Transpiration in Tomato (*Lycopersicon esculentum* L.). *J. Hort. Sci. Biotech.,* **79**: 211–218.
22. Liebersbach, H., Steingrobe, B. and Claassen, N. 2004. Roots Regulate Ion Transport in the Rhizosphere to Counteract Reduced Mobility in Dry Soil. *Plant Soil*. **260**: 79–88.
23. Lu, S. W., Li, T. and Jing, J. 2010. Effects of Tomato Fruit under Na^+ -Salt and Cl^- Salt Stresses on Sucrose Metabolism. *Afric. J. Agric. Res.*, **5(16)**: 2227-2231.
24. Marschner, H. 1995. Mineral Nutrition of Higher Plants 2nd Edit. Academic Press. London. pp. 299-312.
25. Mohammad, M., Shibli, R., Ajouni, M. and Nimri, L. 1998. Tomato Root and Shoot Responses to Salt Stress under Different Levels of Phosphorus Nutrition. *J. Plant Nutrit.*, **21**: 1667-1680.
26. Munns, R., James, R. A. and Lauchli, A. 2006. Approaches to Increasing the Salt Tolerance of Wheat and Other Cereals. *J. Exp. Bot.*, **57**: 1025–1043.
27. Oztekin G. B. and Tuzel, Y. 2011. Comparative Salinity Responses Among Tomato Genotypes and Rootstocks. *Pak. J. Bot*., **43(6)**: 2665-2672.
28. Qi, Z. and Spalding, E. P. 2004. Protection of Plasma Membrane K+ Transport by the Salt Overly Sensitive1 Na^+-H^+ Antiporter during Salinity Stress. *Plant Physiol.*, **136**: 2547–2555.
29. Rus, A. M., Estan, M. T., Gisbert, C., Garcia-Sogo, B., Serrano, R., Caro, M., Moreno, V. and Boları´n, M. C. 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.
30. Sairam, R. K., Rao, K. V. and Srivastava, G. C. 2002. Differential Response of Wheat Genotypes to Long Term Salinity Stress in Relation to Oxidative Stress, Antioxidant Activity and Osmolytes Concentration. *Plant Sci.*, **163**: 1037-1046.
31. Santa-Cruz, A., Acosta, M., Rus, A. and Bolarin, M. C. 2002. Short-term Salt Tolerance Mechanisms in Differentially Salt Tolerant Tomato Species. *Plant Physiol.*, **19**: 331–340.
32. Stepien, P, and Kłbus, G. 2006. Water Relations and Photosynthesis in *Cucumis sativus* L. Leaves under Salt Stress. *Biolog. Plantarum*, **50**: 610-616.
33. Tantawy, A. S., Abdel-Mawgoud, A. M. R., El-Nemr, M. A., Chamoun, Y. G. 2009. Alleviation of Salinity Effects on Tomato Plants by Application of Amino-acids and Growth Regulators. *Eur. J. Sci. Res.,* **30(3)**: 484-494.
34. Telesiñski, A., Nowak, J., Smolik, B., Dubowska, A. and Skrzypiec, N. 2008. Effect of Soil Salinity on Activity of Antioxidant Enzymes and Content of Ascorbic Acid and Phenols in Bean (*Phaseolus vulgaris* l.) plants. *J. Elementol*, **13(3)**: 401-409
35. Trehan, S. P., El-Dessougi, H. and Claassen, N. 2005. Potassium Efficiency of 10 Potato Cultivars as Related to Their Capability to Use Nonexchangeable Soil Potassium by Chemical Mobilization. *Comm. Soil Sci. Plant Anal.*, **36**: 1809–1822.
36. Yamaguchi, T. and Blumwald, E. 2005. Developing Salt Tolerant Crop Plants:

Challenges and Opportunities. *Trends Plant Sci.*, **10(12)**:615-620.
37. Yang, X. E., Liu, J. X., Wang, W. M., Ye, Z. Q. and Luo, A.C. 2004. Potassium Internal use Efficiency Relative to Growth Vigor, Potassium Distribution, and Carbohydrate Allocation in Rice Genotypes. *J. Plant Nutrit.,* **27**: 837–852
38. Yilmaz, J. L. 2004. Abiotic Stress Tolerance: Metabolic and Physiological Effects of Compatible Solutes and Calmodulin on E. coli and Tobacco. In: "*Pure and Applied Biochemistry*", (Ed): J. L. Yilmaz, Lund University, Lund, Sweden, PP. 1-40.
39. Yokas, I, Tuna, A. L., Burun, B., Altunlu, H., Altana, F. and Kaya, C. 2008. Responses of the Tomato (*Lycopersicon esculentum* Mill.) Plant to Exposure to Different Salt Forms and Rates. *Turk. J. Agric.*, **(32)**: 319-329.
40. Zhang, J. F., Yuan, Y., Niu, C., Hinchliffe, D. J., Lu, Y., Yu, S. X., Ulloa, M., Percy, R.G. and Cantrell, R.G. 2007. AFLP-RGA Markers in Comparison with RGA and AFLP in Cultivated Tetraploid Cotton. *Crop Sci.,* **47**:180–187.
41. Zhao, G. Q., Ma, B. L. and Ren, C. Z. 2007. Growth, Gas Exchange, Chlorophyll Fluorescence, and Ion Content of Naked Oat in Response to Salinity. *Crop Sci.*, **47**: 123–131.

تشخیص پاسخ های متفاوت پانزده ژنوتیپ گوجه فرنگی (*Lycopersicon esculentum* Mill.) به تنش سدیم کلراید

م. امجد، ج. اختر، م. انورالحق، ر. احمد، و م. زاید

چکیده

به منظور بررسی تحمل ۱۵ ژنوتیپ گوجه فرنگی در سیستم آب کشت به سطوح مختلف سدیم کلراید، آزمایشی با میزان صفر، ۷۵ و ۱۵۰ میلی مول سدیم کلراید در محلول غذایی هوگلند انجام شد. آزمایش در قالب طرح آزمایشی کاملا تصادفی (CRD) با سه تکرار انجام شد. پس از سی روز اعمال تنش شوری پارامترهای تبادل گازی شامل میزان تعرق، هدایت روزنه ای، میزان ثبت کربن و فتوسنتز ، غلظت دی اکسید کربن بین سلولی، و همچنین مشخصات رشدی گیاهان برداشت شده (شامل نسبت شاخه به طولانی ترین ریشه و نسبت وزن تر به وزن خشک) و مشخصات یونی (K^+, Na^+ و نسبت K^+به $Na+$) اندازه گیری گردید. همه پارامترهای رشدی و تبادلات گازی با افزایش غلظت سدیم کلراید کاهش را نشان دادند. اگرچه این کاهش در ژنوتیپ هایی که به تنش شوری تحمل بیشتری داشتند در مقایسه با ژنوتیپ های حساس ، کاهش کمتری داشتند. همچنین مشاهده گردید که با افزایش غلظت NaCl در محیط کشت میزان Na^+ در بافت گیاهی افزایش و میزان یون k^+ کاهش پیدا کرد. بنابر این چنین نتیجه گیری شد که گیاهانی که قدرت جذب k^+بیشتری داشتند، با نسبت بالاتری از k^+/Na^+ ، همچنین رشد رویشی بیشتری برخوردار بودندمقاومت بیشتری را نسبت به تنش شوری نشان دادند. همچنین نتایج نشان داد وزن تر و خشک، مشخصه های تبادل گازی، و نسبت k^+/Na^+از مولفه های

موثر در تشخیص تحمل به شوری در گوجه فرنگی هستند. با توجه به پاسخ ژنوتیپ‌های مورد مطالعه ژنوتیپ ایندنت-۱ و ناگنیا به عنوان ژنوتیپ های متحمل و ژنوتیپ های رد بال و تپو-۸۶ حساس در شرایط تنش شوری هستند.