Turkish Journal of Biology

Volume 38 | Number 2 Article 7

1-1-2014

Soil and foliar application of potassium enhances fruit yield and quality of tomato under salinity

MUHAMMAD AMJAD

JAVAID AKHTAR

MUHAMMAD ANWAR UL HAQ

SHAKEEL IMRAN

SVEN-ERIK JACOBSEN

Recommended Citation

AMJAD, MUHAMMAD; AKHTAR, JAVAID; HAQ, MUHAMMAD ANWAR UL; IMRAN, SHAKEEL; and JACOBSEN, SVEN-ERIK (2014) "Soil and foliar application of potassium enhances fruit yield and quality of tomato under salinity," *Turkish Journal of Biology*: Vol. 38: No. 2, Article 7. https://doi.org/10.3906/biy-1305-54
Available at: https://journals.tubitak.gov.tr/biology/vol38/iss2/7

Turkish Journal of Biology

http://journals.tubitak.gov.tr/biology/

Research Article

Turk J Biol
(2014) 38: 208-218
© TÜBİTAK
doi:10.3906/biy-1305-54

Soil and foliar application of potassium enhances fruit yield and quality of tomato under salinity

Muhammad AMJAD[1,2,*], Javaid AKHTAR[1], Muhammad ANWAR-Ul-HAQ[1], Shakeel IMRAN[3], Sven-Erik JACOBSEN[2]
[1]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
[2]Department of Plant and Environmental Sciences, Faculty of Sciences, University of Copenhagen, Tåstrup, Denmark
[3]Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan

Received: 21.05.2013 • **Accepted:** 14.11.2013 • **Published Online:** 28.03.2014 • **Printed:** 28.04.2014

Abstract: Potassium plays a key role in the survival of plants under saline conditions in mitigating the adverse effects of sodium. The effect of application of potassium to soil (0, 3.3, and 6.6 mmol/kg) and leaves (4.5 and 9 mM) on tomato yield and quality under 3 salinity treatments (0, 7.5, and 15 dS m^{-1}), using 2 salt-tolerant (Indent-1 and Nagina) and 2 salt-sensitive (Peto-86 and Red Ball) genotypes, was studied in a pot experiment. Salinity decreased growth and yield of all genotypes; however, salt-tolerant genotypes maintained better growth and produced higher yield than the salt-sensitive genotypes across all salinity levels. Potassium application positively affected plant growth and yield, especially in salt-tolerant genotypes. Fruit quality characteristics (total soluble solids, titratable acidity, pH, dry matter %) were significantly improved by increasing salinity, except for fruit size. Soil and foliar K had nonsignificant differences between them; however, there were significant effects on the fruit quality, as all characteristics increased at higher K concentrations under salinity stress. It was concluded that the application of potassium increases yield and quality of tomato fruits in saline soil, and it could be used as an effective practice to produce even a salt-sensitive species like tomato under saline conditions.

Key words: Salt tolerance, potassium, *Solanum lycopersicum* L., total soluble solids, titratable acidity

1. Introduction

Crop production in fields is restricted by a number of abiotic stress factors like drought, salinity, light intensity, and temperature. Soil salinization is among the most severe abiotic threats to agriculture. According to a study on global land use patterns, 7% of the earth's total land area (1000 × 10^6 ha) has become saline (Tester and Davenport, 2003).

Soil salinity not only affects plant growth but also developmental processes like seed germination, seedling vigor, flowering, and seed setting, primarily because of hyperosmotic stress and ionic imbalance (Sairam and Tyagi, 2004; Demiral et al., 2005). The increased osmotic pressure in the root environment decreases the availability of water to plants and its movement to reproductive organs such as fruits, and, as a result, fruit size is decreased, as seen in tomato and other crops (Li and Stanghellini, 2001; Mavrogianopoulos et al., 2002).

Tomato (*Solanum lycopersicum* L., previously named *Lycopersicon esculentum* Mill.) is an important crop in several parts of the world, including the regions suffering from drought and soil salinity, such as the Mediterranean region, where these aspects have been studied (Savic et al., 2009; Jensen et al., 2010). Tomato is not regarded as tolerant to abiotic stress factors, but these stresses, such as salinity, may enhance fruit quality by increasing sugar concentration and dry matter content (Yurtseven et al., 2005).

Potassium is one of the important macronutrients required for the growth, development, yield, and quality of plants, and it also plays a key role in the survival of plants under abiotic stress conditions, as stress negatively affects the physiological processes of plants such as root and shoot elongation, enzyme activity, water and assimilate transport, synthesis of protein, photosynthetic transport, and chlorophyll content (Yin and Vyn, 2003; Véry and Sentenac, 2003; Pettigrew, 2008; Gerardeaux et al., 2010; Kanai et al., 2011). Under saline field conditions, plants suffer a deficiency of potassium mainly because of the excess of Na^+ in the rooting medium, which acts as an antagonist and decreases the availability of potassium (Niu et al., 1995; Rodriguez-Navarro, 2000); thus, under salinity

---

[*] Correspondence: amjad_ses@yahoo.com

stress, plants face the problem of K deficiency. Therefore, under salinity stress, improving the K-nutritional status of plants alleviates the detrimental effects of Na^+ by different mechanisms, including $K^+ = Na^+$ discrimination (Rodriguez-Navarro, 2000; Rubio et al., 2009).

As higher levels of NaCl cause K-deficiency, this may be one of the factors of oxidative stress. Hence, under salt stress, improving the K-nutritional status of the plants could be used as a tool to minimize oxidative cell damage, at least by the reduced formation of reactive oxygen species during photosynthesis and by the inhibition of NADPH oxidase generating $O_2^{\bullet-}$ (Shen et al., 2000; Shin and Schachtman, 2004). Previous reports suggest that under salinity stress, maintaining a sufficient supply of potassium to the plant alleviates the negative effects of salinity in different crops like strawberry (Kaya et al., 2003; Khayyat et al., 2009); bell pepper (Kaya et al., 2003); maize, wheat, soybean, and cotton (Pettigrew, 2008); and pepper (Rubio et al., 2009). Donald et al. (1998) reported that under water deficit, supplementary potassium via foliar feeding maximized the yield of cotton. Kaya et al. (2001, 2003) reported that foliar application of K fertilizer could be effective in correcting salinity-induced K-deficiency, significantly decreasing salinity-induced damage to membranes and increasing biomass production in tomato and strawberry.

Tomato production in the field is mainly concentrated in the warm and dry areas of the world where irrigation is a necessary practice. Natural and anthropogenic processes in these areas often create soil salinization (Iqbal et al., 2007), which is a major constraint to tomato production (Yurtseven et al., 2005). Salt-affected soils can be utilized for crop production by the leaching of salts below the root zone so that they may not hamper crop production, by the selection and introduction of salt-tolerant cultivars and species, and by the use of soil amendments to alleviate the detrimental effects of salt stress (Yurtseven et al., 2005; Lu et al., 2010). Under current circumstances, it is not feasible to leach salts because of the limited supply of fresh water, so developing techniques to enhance salt tolerance in plants is inevitable, and the application of potassium is a feasible choice not only to enhance salt tolerance but also to improve tomato fruit quality.

In our experiment, we used 4 tomato genotypes differing in salt tolerance (identified in previous experiments) with the objective to study the effect of the application of potassium (soil and foliar) on enhancing salt tolerance and improving tomato fruit yield and quality. The differential response of salt-tolerant (Indent-1 and Nagina) and salt-sensitive (Peto-86 and Red Ball) genotypes to potassium under salt stress was evaluated.

2. Materials and methods

2.1. Experimental setup

A pot experiment was conducted in the glass house of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan, between 5 October 2011 and 21 February 2012. Two sets of tomato (*Solanum lycopersicum* L.) varieties (salt-tolerant and salt-sensitive), namely Indent-1 and Nagina (salt-tolerant) and Peto-86 and Red Ball (salt-sensitive), were used in this experiment. These varieties were screened for salt tolerance in our previous experiments based on different growth, physiological, gas exchange, and ionic characteristics (Amjad et al., 2013).

The experiment was conducted according to completely randomized design with 3 replicates, using factorial arrangement. Seeds of these 4 genotypes were surface-sterilized with 1% sodium hypochlorite solution and germinated in polythene-lined iron trays filled with quartz sand. Plants at the 5-leaf stage were transferred to ceramic pots having 12 kg of soil. Sandy loam soil was collected from the upper surface of soil (15 cm deep), air-dried, ground, sieved through a 2-mm mesh screen, and analyzed for different physiochemical characteristics (Table 1). Different levels of salinity (0, 7.5, and 15 dS m^{-1}) and K (0, 3.3, and 6.6 mmol/kg) were added by mixing calculated amounts of NaCl and KNO_3 in a mechanical mixer along with 2 levels of foliar potassium (4.5 and 9 mM) at 25-day intervals. Soil bulk density was taken into consideration while making the fertilizer calculations for the whole of the pot depth (30 cm). The 0 mmol/kg K and 0 dS m^{-1} salinity treatments showed that there were basic contents of potassium and NaCl, and no additional potassium or NaCl was applied. For potassium levels, KNO_3 was used because other forms like KCl could change the salinity levels with their anions. Recommended doses of N and P fertilizer at the rates of 210 and 125 kg ha^{-1} respectively were applied, and the amount of N added in the form of KNO_3 was taken into consideration while making final calculations. No additional Ca, Mg, S, or B fertilizers were applied, as the basic soil contents of these nutrients in the soil were enough to support tomato plant growth (Table 1). Plants were irrigated with tap water; plant water requirements were determined by visually observing the soil moisture status, and the amount of water required to irrigate 12 kg of soil was determined before the experiment. Characteristics of the water used are given in Table 1.

2.2. Plant biomass, fruit yield, and quality

Plants were harvested once when ≥90% of the fruits had turned red (150 days). Plant height was measured, and the maximum number of bunches each plant had were counted; for determining plant dry mass, samples were placed in an oven at 65 ± 5 °C. Fruit yield and quality

Table 1. Physical and chemical properties of soil (15 cm deep) and water used in the experiment.

Soil characteristics	
Average bulk density (Mg/m^{-3})	1.15
pH$_s$	7.59
Sodium adsorption ratio	2.98 (mmol L^{-1})$^{1/2}$
EC (dS m^{-1})	1.37
N (mmol/kg)	96.0
P (mmol/kg)	1.14
K (mmol/kg)	2.50
Ca (mmol/kg)	27.0
Mg (mmol/kg)	17.7
S (mmol/kg)	1.17
B (mmol/kg)	0.20
Organic material (%)	1.04
Texture (%)	Sandy loam
Sand	58
Clay	20
Silt	22
Irrigation water characteristics	
Electrical conductivity	0.79 (dS m^{-1})
pH	7.06
Residual sodium concentration	1.12 mmol L^{-1}

parameters like fruit number per plant, fruit weight per plant, average fruit weight, fruit diameter, fruit height, and dry matter percentage were recorded.

2.3. Fruit juice characteristics

Ten fruits per plant were used for the measurement of fruit juice characteristics like pH, total soluble solids (TSS; Brix), and titratable acidity (TA).

Brix was measured with a digital hand-held "Pocket" refractometer (PAL-Alpha; Cat. No. 3840). TA of fruit juice was measured by titration method according to the American Association of Analytical Chemists (2000) using 0.1 M NaOH. To 9 mL of filtered fruit juice, 1 mL of distilled water was added; it was titrated against 0.1 M NaOH using phenolphthalein as the indicator.

2.4. Leaf sap ionic analysis

For leaf ionic analysis (Na^+ and K^+), fresh leaves were frozen and thawed. Thawed leaves were crushed with a stainless steel rod in microcentrifuge tubes and leaf sap was collected. The leaf sap was then centrifuged at 6500 rpm for 10 min; supernatant was collected and used for Na^+ and K^+ determination (Gorham, 1984). The concentration of Na^+ and K^+ was determined with a flame photometer (Sherwood Flame Photometer, Model-410; Sherwood Scientific Ltd., Cambridge, UK) using the standard curve made by different concentration readings of NaCl and KCl.

2.5. Leaf macronutrient determination

For total nitrogen determination, plant material was digested in a sulfuric–salicylic acid mixture and subsequently distilled on a Kjeldahl N-apparatus, and total N was calculated (Buresh et al., 1982). Total phosphorus was determined using the spectrophotometric method by recording the absorbance (Jones et al., 1991); Ca and Mg were determined by atomic absorption spectroscopy (Chapman and Pratt, 1961)

2.6. Statistical analysis

Data were analyzed for analysis of variance with Statistix 8.0 software and presented as mean of 3 replicates ± SE, and significance was checked at $P \leq 0.05$.

3. Results

Plants were harvested when ≥90% of the fruits had turned red, and different plant growth, fruit yield, and quality characteristics were measured. For convenience and better understanding of the effects of salinity and potassium on tomato, genotypes were divided into 2 groups: the salt-tolerant (Indent-1, Nagina) and the salt-sensitive (Peto-86, Red Ball). Results showed that behavior of genotypes was similar within the same salinity tolerance group, i.e. genotypes Indent-1 and Nagina in the salt-tolerant group followed the same trend and showed nonsignificant differences between them in all parameters; the case was similar with Peto-86 and Red Ball in the salt-sensitive group. For simplicity, the results presented are of 2 genotypes instead of 4, representing each group, i.e. 1 from the salt-tolerant group (Indent-1) and 1 from the salt-sensitive group (Red Ball). Table 2 represents the analysis of various results of different parameters in response to treatments.

3.1. Plant growth characteristics

At harvest, plant height was recorded in response to different treatments of salinity (0, 7.5, and 15 dS m^{-1}) and potassium both in the form of soil (0, 3.3, and 6.6 mmol/kg) and foliar (4.5 and 9 mM) applications in salt-tolerant and salt-sensitive groups (Figure 1). Increasing salinity levels significantly ($P \leq 0.05$) reduced plant height in both groups; however, a significant difference in plant height between salt-tolerant and salt-sensitive groups was recorded both in the control (0 dS m^{-1}) and salt-stressed (7.5 and 15 dS m^{-1}) plants. The decrease in plant height was significantly higher in the salt-sensitive group as compared to the salt-tolerant group.

Table 2. Mean squares of treatments for different parameters.

Parameter	Mean square	F-value
Plant height	1587.70	147.10*
Plant dry weight	107.210	300.46*
Leaf Na content	13,112.1	466.51*
Leaf K content	16,404.1	119.02*
Leaf K:Na	30.3316	347.65*
Leaf N	2.4706	149.47*
Leaf P	0.04088	132.85*
Leaf Ca	2.82639	131.42*
Leaf Mg	2,953,937	132.85*
Fruit yield per plant	122,550	223.52*
Titratable acidity	362,030	40.81*
Fruit dry matter	20.9576	163.51*
Fruit no.	101.593	130.62*
TSS	16.9407	118.94*

*: $P < 0.05$.

Application of potassium in both the soil and foliar forms alleviated the negative effects of salinity and resulted in a significant increase in plant height of both salt-tolerant and salt-sensitive groups as compared to respective controls. The effect of potassium was much more pronounced in the salt-stressed than in the nonstressed plants, but the effect of soil and foliar application of potassium was not significant.

A significant difference in plant dry weight was observed in all 4 tomato genotypes (Figure 1). Although at higher levels of salt stress (7.5 and 15 dS m^{-1}) plant dry weight significantly decreased in both salt-tolerant (Indent-1 and Nagina) and salt-sensitive (Peto-86 and Red Ball) groups, it was significantly higher ($P \leq 0.05$) in the salt-tolerant group than the salt-sensitive group at all salinity levels. Potassium application (soil and foliar) positively affected the plant dry weight, and it was significantly increased in response to both levels of potassium application at 15 dS m^{-1} as compared to the control; however, at 7.5 dS m^{-1}, it was only significant at higher potassium concentrations (6.6 mmol/kg and 9 mM). There was no significant difference between soil and

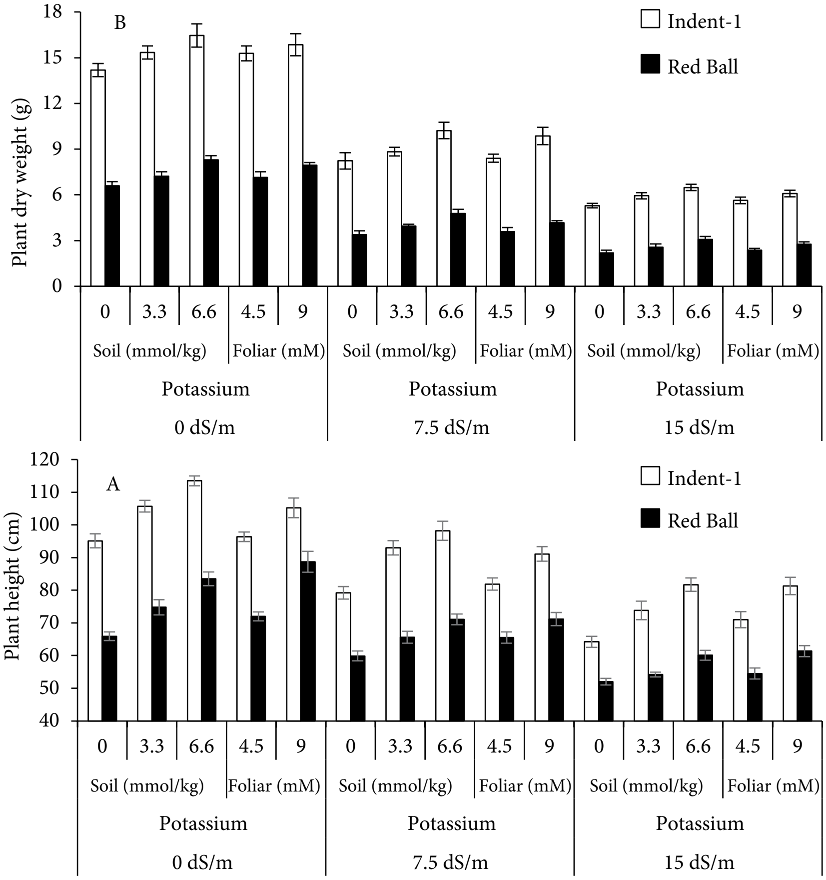

Figure 1. Plant height (A) and plant dry weight (B) response of salt-tolerant and salt-sensitive tomato genotypes to different levels of potassium (0, 3.3, and 6.6 mmol/kg, soil; 4.5 and 9 mM, foliar) and salinity (0, 7.5, and 15 dS m^{-1}).

foliar applications of potassium or between the levels of potassium. Plant growth was linearly correlated to plant leaf ionic concentrations (Figure 2); tomato plant growth was negatively affected by leaf Na^+ concentration, as evident from the correlation coefficients between leaf Na^+ and plant height ($r^2 = 0.6240$) and dry weight ($r^2 = 0.7394$), while it was positively related to leaf K^+ concentration with correlation coefficients between leaf K^+ and plant height ($r^2 = 0.9138$) and plant dry weight ($r^2 = 0.9092$).

3.2. Plant leaf ionic content

With increasing salinity from 0 to 7.5 and 15 dS m^{-1}, leaf Na^+ concentration significantly increased, whereas K^+ concentration significantly decreased in both the salt-tolerant (Indent-1 and Nagina) and salt-sensitive (Peto-86 and Red Ball) groups (Figure 3). However, the salt-tolerant group had significantly lower values of Na^+ and higher values of K^+ concentration than the salt-sensitive group. Potassium application acted conversely, and significantly increased the leaf K^+ and decreased the leaf Na^+ concentration, with more pronounced effects in the salt-tolerant group as compared to the salt-sensitive group. With these antagonistic effects between salinity and potassium application, the ratio between leaf K^+ and Na^+ (K^+/Na^+) decreased with increasing salinity (7.5 and 15 dS m^{-1}), and it increased with increasing potassium application (both soil and foliar) in both the salt-tolerant and salt-sensitive groups, with significantly higher values in the salt-tolerant group (Figure 3).

3.3. Plant leaf macronutrient status

Foliar and soil application effects on plant macronutrient status (N, P, Ca, Mg) are presented in Figure 4. Generally, increasing salinity in the soil from 0 dS m^{-1} to 15 dS m^{-1} significantly decreased the plant macronutrient concentrations in both the salt-tolerant and salt-sensitive groups, with a significantly greater decrease in the salt-sensitive group compared to the salt-tolerant group. Potassium application to both soil and leaves significantly increased the leaf macronutrient concentrations, with significantly higher concentrations in the salt-tolerant group.

3.4. Fruit yield parameters

Fruit yield parameters, measured in terms of fruit weight per plant, are presented in Figure 5. Plants had a maximum number of 5 bunches of fruits and a maximum of 7 fruits per bunch. Generally, with increasing salinity

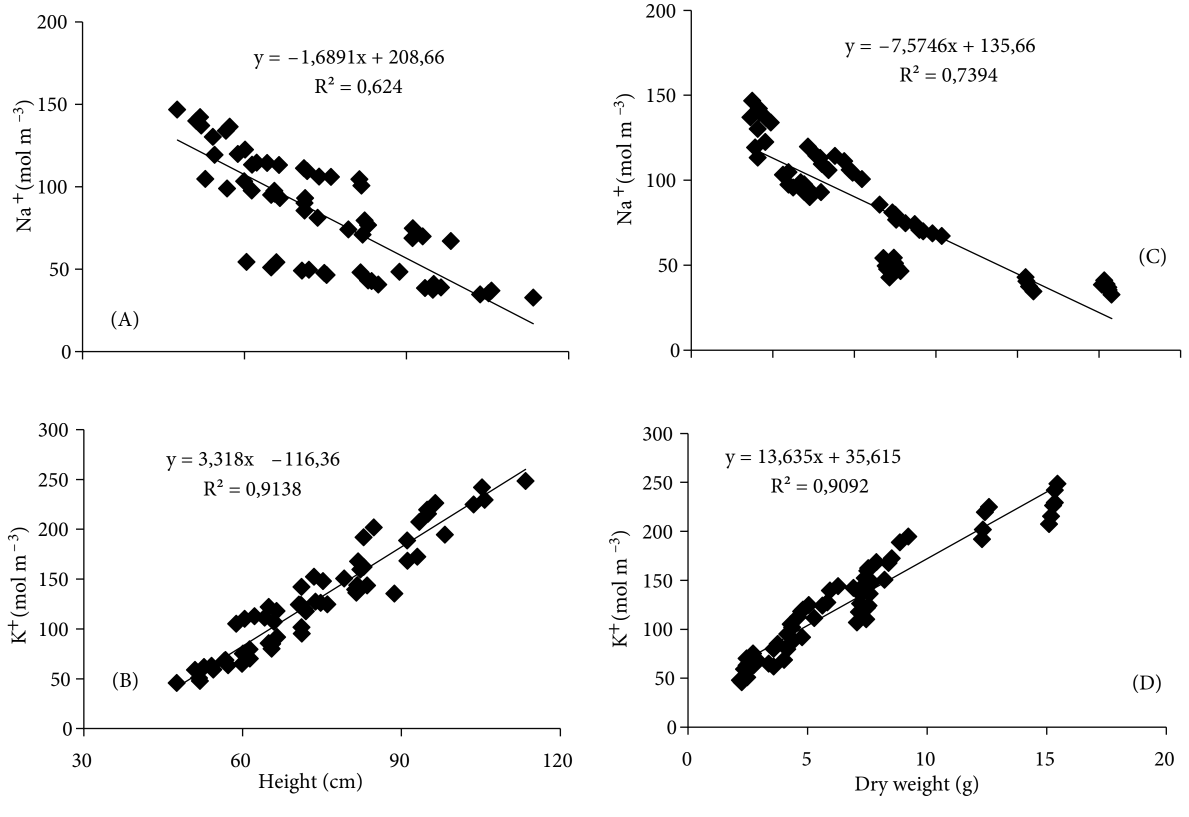

Figure 2. Relationship between leaf sap ionic concentrations (Na^+ and K^+) and plant growth characteristics (plant height and plant dry weight): A) relationship between leaf sap Na^+ and plant height; B) relationship between leaf sap K^+ and plant height; C) relationship between leaf sap Na^+ and plant dry weight; D) relationship between leaf sap K^+ and plant dry weight. All values are means of 3 replicates.

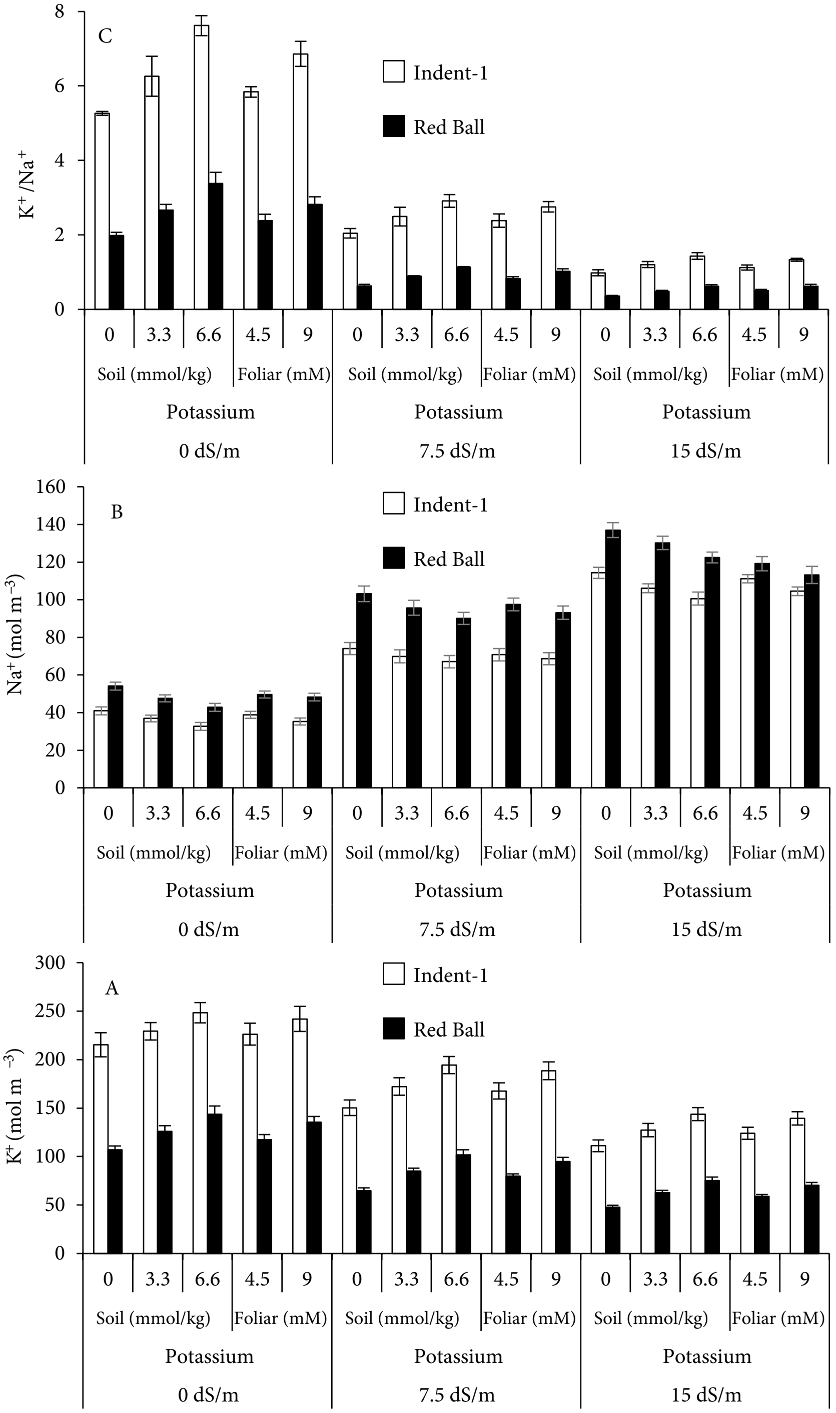

Figure 3. Leaf sap K^+ (A), Na^+ (B), and K^+/Na^+ (C) concentrations in salt-tolerant and salt-sensitive tomato genotypes at different levels of potassium (0, 3.3, and 6.6 mmol/kg, soil; 4.5 and 9 mM, foliar) and salinity (0, 7.5, and 15 dS m^{-1}).

stress (7.5 and 15 dS m^{-1}), fruit weight per plant, average fruit weight (data not shown), and fruit number per plant decreased significantly ($P \leq 0.05$) in both the salt-tolerant (Indent-1 and Nagina) and salt-sensitive (Peto-86 and Red Ball) groups. However, the salt-tolerant group maintained significantly higher values for these fruit yield characteristics than the salt-sensitive group in both the salt-stressed and nonstressed plants.

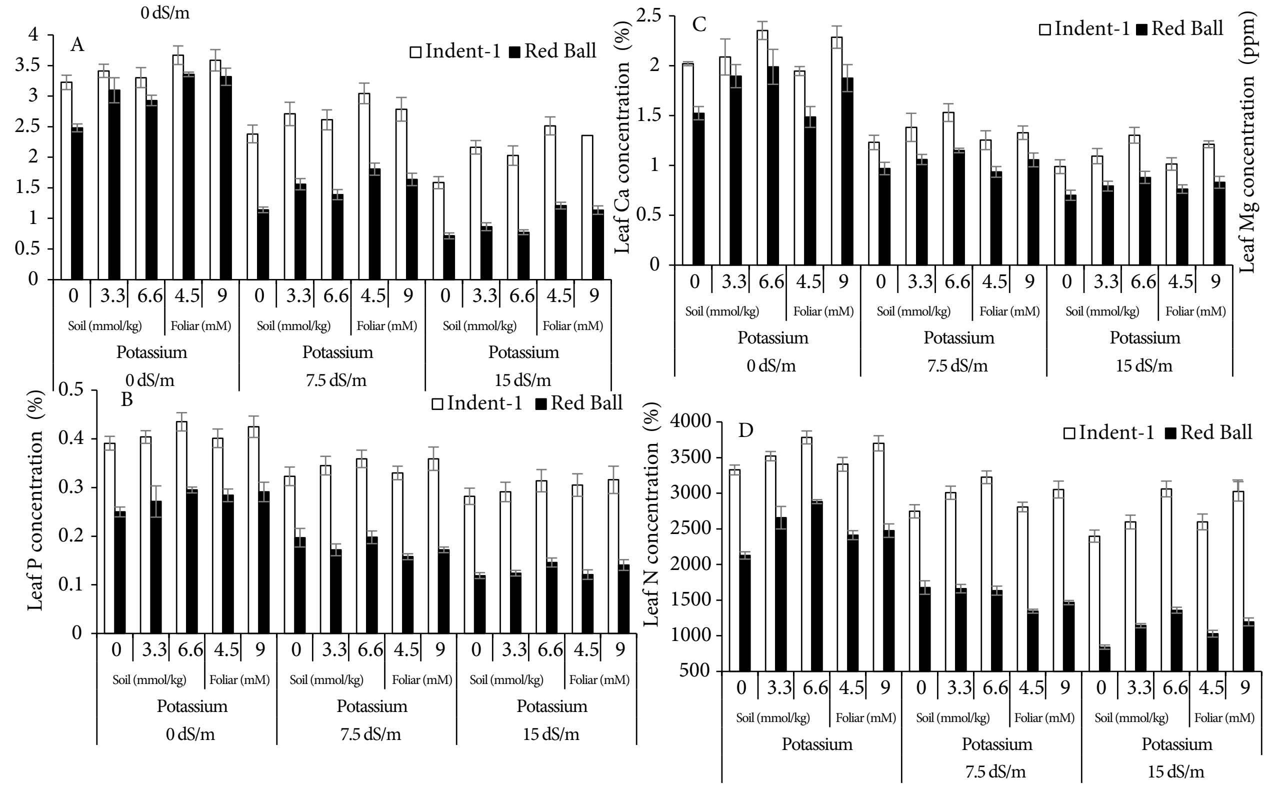

Figure 4. Leaf tissue macronutrient concentrations of N (A), P (B), Ca (C), and Mg (D) of salt-tolerant and salt-sensitive tomato genotypes at different levels of potassium (0, 3.3, and 6.6 mmol/kg, soil; 4.5 and 9 mM, foliar) and salinity (0, 7.5, and 15 dS m^{-1}).

Application of potassium had a significant positive effect on the fruit yield of tomato plants in both control and salt-stressed plants. The effect of potassium was much more pronounced in the salt-tolerant group than in the salt-sensitive group. The effect of form of application of potassium (soil and foliar) also differed significantly for all salt treatments in all genotypes.

3.5. Fruit quality characteristics

3.5.1. Fruit size

At harvest, fruit size was measured in terms of average fruit diameter and height in response to different levels of salinity and potassium in both the salt-tolerant and salt-sensitive groups (data not shown). A significant decrease ($P \leq 0.05$) in fruit diameter and height was observed with increasing soil salinity (7.5 and 15 dS m^{-1}) in both the salt-tolerant (Indent-1 and Nagina) and salt-sensitive (Peto-86 and Red Ball) groups. However, higher levels of potassium application, both soil (3.3 and 6.6 mmol/kg) and foliar (4.5 and 9 mM), significantly decreased the negative effects of salinity and induced a significant increase in fruit diameter and height. In addition, significant differences were observed in the forms of application of potassium (soil and foliar) in all genotypes and in all salt treatments. Among the genotypes, the salt-tolerant group performed better and had greater fruit diameter and height both in the control and salt-treated plants as compared to the salt-sensitive group. A highly significant negative correlation coefficient was found between leaf Na^+ and fruit weight per plant ($r^2 = 0.8670$) and diameter ($r^2 = 0.6858$), whereas a positive correlation was found between K^+ and fruit weight per plant ($r^2 = 0.8646$) and diameter ($r^2 = 0.8856$).

3.5.2. TSS (Brix) and fruit dry matter (%)

TSS and fruit dry matter as a measure of tomato fruit quality increased significantly from the control (0 dS m^{-1}) to salt stress (7.5 and 15 dS m^{-1}) in both the salt-tolerant (Indent-1 and Nagina) and salt-sensitive (Peto-86 and Red Ball) groups (Figure 5). Plants in the control treatment (0 mM K) showed significantly lower values of these fruit quality characteristics than the K-treated plants at all 3 saline levels (0, 7.5, and 15 dS m^{-1}). Application of potassium both in soil (3.3 and 6.6 mmol/kg) and foliar (4.5 and 9 mM) form had significant differences within different concentrations; it significantly increased the TSS and fruit dry matter in all genotypes compared to the control (0 mM K). Among the genotypes, the salt-tolerant group had a higher percentage of TSS and fruit dry matter in all the saline treatments than the salt-sensitive group; furthermore, the response of the salt-tolerant group to

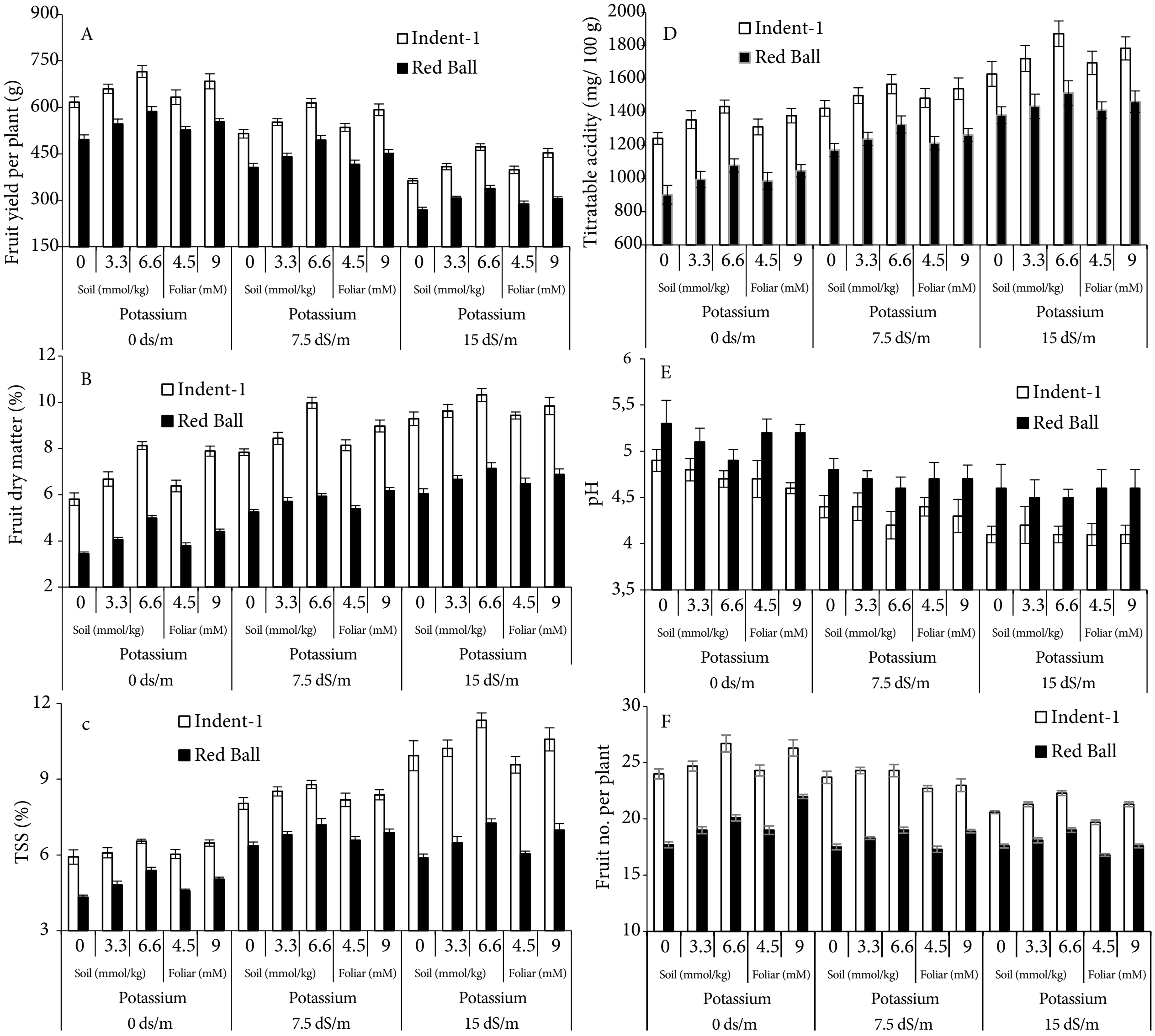

Figure 5. Fruit yield per plant (A), fruit dry matter (B), TSS (C), titratable acidity (D), fruit juice pH (E), and number of fruits per plant (F) of salt-tolerant and salt-sensitive tomato genotypes at different levels of potassium (0, 3.3, and 6.6 mmol/kg, soil; 4.5 and 9 mM, foliar) and salinity (0, 7.5, and 15 dS m^{-1}).

different concentrations of potassium was significantly higher than in the salt-sensitive group.

3.5.3. TA and pH of fruit juice

TA and pH of the fruit juice, measured as indicators of the sourness of the tomato, are presented in Figure 5. Generally, increasing concentrations of salinity (7.5 and 15 dS m^{-1}) and potassium in both soil (3.3 and 6.6 mmol/kg) and foliar (4.5 and 9 mM) forms caused a significant ($P \leq 0.05$) increase in the titratable acidity of the tomato fruit juice as compared to respective controls in all genotypes. However, the salt-tolerant group (Indent-1 and Nagina) showed significantly higher values of titratable acidity than the salt-sensitive group (Peto-86 and Red Ball). There were nonsignificant differences between different potassium concentrations within the same salinity treatment in all the genotypes.

In the case of pH of the fruit juice, soil salinity (7.5 and 15 dS m^{-1}) caused significant decreases in all genotypes as compared to controls (0 dS m^{-1}). While potassium application had no effect on the pH of fruit juice within all the saline levels, it significantly decreased the pH at higher salinity levels (7.5 and 15 dS m^{-1}) in all genotypes when compared to controls at the respective potassium level. Among the tomato genotypes, the salt-tolerant group

(Indent-1 and Nagina) had significantly lower values of fruit juice pH than the salt-sensitive (Peto-86 and Red Ball) group at all the saline and potassium levels; however, the values were nonsignificant within the salt-tolerant and salt-sensitive groups.

4. Discussion

Salt stress severely limits yield from tomato plants. In the current study, salt stress (7.5 and 15 dS m^{-1}) significantly decreased the growth of the tomato plants measured in terms of plant height and dry weight. This could be the result of drought due to excess amounts of salt in the root zone, which leads to reduced photosynthetic capacity, or toxicity of salt in plant tissues (Sairam et al., 2002; Natr and Lawlor, 2005; Neocleous and Vasilakakis, 2007). The increase in growth parameters with the application of potassium could be the result of antagonism between K^+ and Na^+ ions in the root zone (Chen et al., 2007). Potassium acted as an ameliorative agent and decreased the negative effects of NaCl in the growth medium, and resulted in the better growth of plants, as evident from the significant negative correlation between the growth parameters of plant height and plant dry weight ($r^2 = 0.624, 0.7394$) and leaf sap Na^+, and the significant positive correlation ($r^2 = 0.9138, 0.9092$) with leaf sap K^+, respectively. These results are consistent with previous findings in tomato (Kaya et al., 2001; Azarmi et al., 2010), as well as in rice (Ikeda et al., 2004), and cucumber and pepper (Kaya et al., 2003).

In this experiment, results showed that with increasing salinity, the yield of tomato declined in both the salt-tolerant and salt-sensitive groups. This reduction in yield was caused by reduced mean fruit weight as salinity caused reduced water availability and biochemical and physiological disturbances in the rooting medium (Cuartero et al., 2006; Azarmi et al., 2010). Application of potassium increased the yield under salt stress as it reduced the negative effects of salinity (Figure 6). Soil salinity and the application of potassium increased the size (Figure 6) and the quality of tomato fruits as measured by TSS, TA, pH, and dry matter in all genotypes, consistent with the findings of Azarmi et al. (2010) and Yurtseven et al. (2005). All fruit quality characteristics like TSS, dry matter percent, TA, and pH of fruit juice were positively affected by salinity and potassium except for the fruit size (height and diameter), which decreased with increasing salinity and increased with increasing potassium concentration.

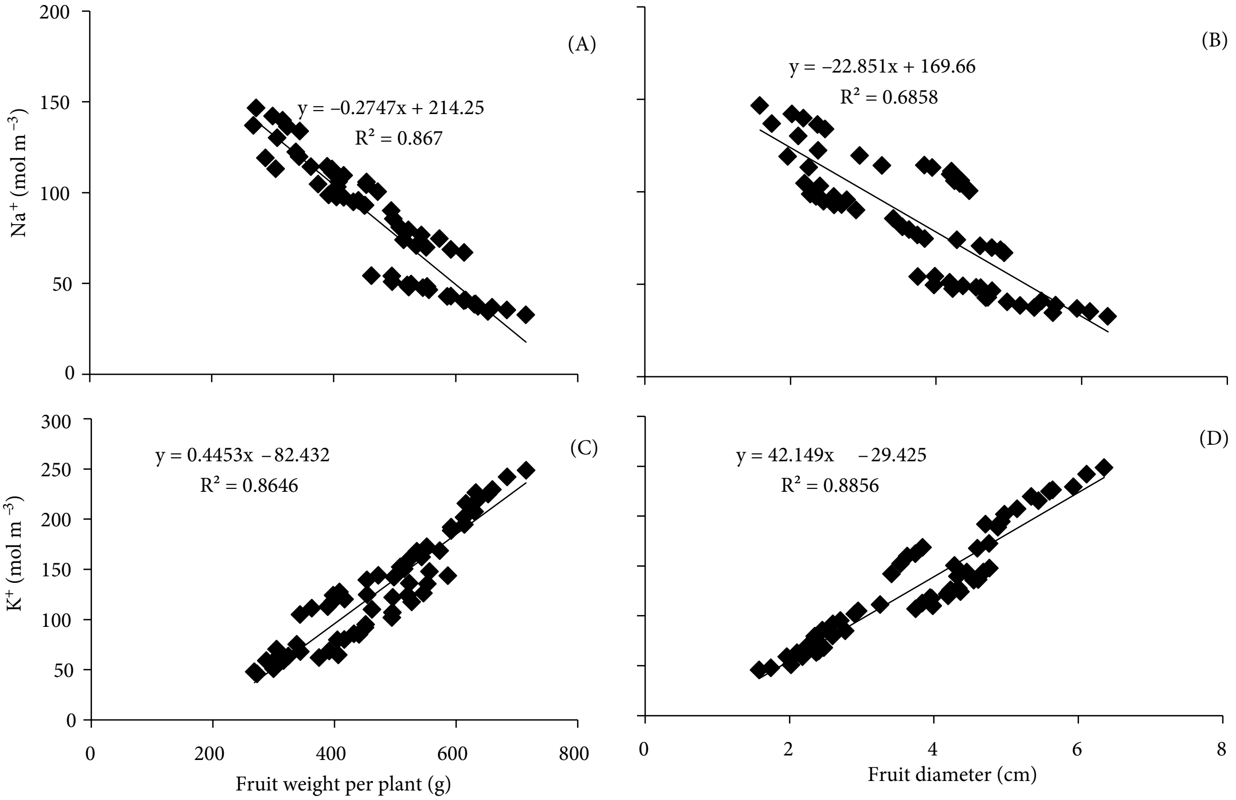

Figure 6. Relationship between leaf sap ionic concentrations (Na^+ and K^+) and fruit yield (fruit weight per plant and average fruit weight) and size (fruit diameter) characteristics: A) Relationship between leaf sap Na^+ and fruit weight per plant; B) relationship between leaf sap Na^+ and fruit diameter; C) relationship between leaf sap K^+ and average fruit weight per plant; D) relationship between leaf sap K^+ and fruit diameter. All values are means of 3 replicates.

Reduction in fruit size can be attributed to decreased water uptake by roots and transport to fruit due to excess amounts of salts in the rooting medium (Leonardi et al., 2004; Neocleous and Vasilakakis, 2007). The improvement in fruit quality characteristics (TSS, dry matter percent, TA, and pH) in response to salinity stress has been reported as being due to decreased fruit water content and increased concentrations of reducing sugars and acids as compared to nonsaline conditions (Leonardi et al., 2004). The accumulation of reducing sugars and organic acids is responsible for increased TA and decreased pH of the fruit juice. Moreover, the nonsignificant difference in fruit weight between foliar and soil application treatments might be due to high basic soil potassium contents (2.5 mmol/kg), which resulted in an increase in fruit weight when coupled with foliar application of potassium.

Increasing salinity levels caused an increase in Na^+ concentration in leaf tissues and a decrease in the K^+ concentration. As a result, growth and yield of tomato plants in both salt-tolerant and salt-sensitive groups decreased due to a higher concentration of salts in the rooting medium and its accumulation in the tissues. Higher concentrations of salts in the apoplast of cells negatively affected survival, growth, development of cells, and, ultimately, the whole plant, primarily by ionic toxicity and hyperosmolarity. Saline soils are dominated by Na^+ and Cl^-; both of these ions have an inhibitory effect on the processes going on in the cytosol and other organelles of cells (Niu et al., 1995; Serrano et al., 1999; Hasegawa et al., 2000; Kato et al., 2001; Zhu, 2002). Wyn Jones and Pollard (1983) reported that a salt concentration of >0.4 M causes the inhibition of enzymes by disturbing the hydrophobic–electrostatic balance necessary to maintain the protein structure. Secondarily, salinity also affects the growth of plants by disturbing the K-nutrition, thus impairing photosynthesis, membrane function, and generation of reactive oxygen species (Hasegawa et al., 2000; Rodriguez-Navarro, 2000; Zhu, 2003; Shabala et al., 2012). As was the case in this experiment, salinity caused a significant decrease in plant growth and yield by an excess of Na^+, but application of potassium both in soil and foliar form alleviated these toxic effects of salinity and induced a significant increase in the growth, yield, and fruit quality of tomato.

In conclusion, the results obtained in this experiment showed that different levels of soil salinity caused a significant decrease in tomato growth and yield in all 4 genotypes, whereas fruit quality was improved under increasing soil salinity. Salt-tolerant genotypes (Indent-1 and Nagina) maintained higher growth, yield, and fruit quality compared to salt-sensitive genotypes (Peto-86 and Red Ball). Potassium application positively affected growth, yield, and fruit quality of tomato under salinity stress. Thus, the use of salt-tolerant genotypes, and an increased application of potassium, could be used as an effective approach to economically utilize salt-affected soils for tomato production.

Acknowledgment

We are very thankful to the Higher Education Commission of Pakistan for funding this project.

References

Amjad M, Akhtar J, Haq MA, Ahmad R (2013). Characterization of comparative response of fifteen tomato (*Lycopersicon esculentum* Mill.) genotypes to NaCl stress. J Agric Sci Technol (in press).

Azarmi R, Taleshmikail RD, Gikloo A (2010). Effects of salinity on morphological and physiological changes and yield of tomato in hydroponics system. J Food Agric Environ 8: 573–576.

Buresh RJ, Austin ER, Craswell ET (1982). Analytical methods in N-15 research. Fert Res 3: 37–62.

Chapman HD, Pratt PF (1961). Methods of Analysis for Soils, Plants and Waters. Berkeley, CA, USA: University of California Press.

Chen Z, Zhou M, Newman I, Mendham N, Zhang G, Shabala S (2007). Potassium and sodium relations in salinised barley tissues as a basis of differential salt tolerance. Funct Plant Biol 34: 150–162.

Cuartero MC, Bolarín MJ, Moreno V (2006). Increasing salt tolerance in the tomato. J Exp Bot 57: 1045–1058.

Demiral MA, Aydın M, Yorulmaz A (2005). Effect of salinity on growth chemical composition and antioxidative enzyme activity of two malting barley (*Hordeum vulgare* L.) cultivars. Turk J Biol 29: 117–123.

Gerardeaux E, Jordan-Meille L, Constantin J, Pellerin S, Dingkuhn M (2010). Changes in plant morphology and dry matter partitioning caused by potassium deficiency in *Gossypium hirsutum* (L.). Environ Exp Bot 67: 451–459.

Gorham J (1984). Salt tolerance in the Triticae: K^+/Na^+ discrimination in some potential wheat grasses and their amphiploids with wheat. J Exp Bot 45: 441–447.

Hasegawa PM, Versan RAJ, Zhu K, Bonhert HJ (2000). Plant cellular and molecular responses to high salinity. Annu Rev Plant Phys 51: 463–499.

Iqbal M, Akhtar J, Haq MA, Nasim M, Saeed A, Naveed M (2007). Variation in growth and ion uptake in rice cultivars under NaCl stress in hydroponics. Pak J Agr Sci 44: 393–405.

Jensen CR, Battilani A, Plauborg F, Psarras G, Chartzoulakis K, Janowiak F, Stikic R, Jovanovic Z, Li G, Qi X et al. (2010). Deficit irrigation based on drought tolerance and root signalling in potatoes and tomatoes. Agr Water Manage 98: 403–413.

Jones JB Jr, Wolf B, Mills HA (1991). Plant Analysis Handbook. Athens, GA, USA: Micro-Macro Publishing, Inc.

Kanai S, Moghaieb RE, El-Shemy HA, Panigrahi R, Mohapatra PK, Ito J, Nguyen NT, Saneoka H, Fujita K (2011). Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in greenhouse tomato prior to its effects on source activity. Plant Sci 180: 368–374.

Kato Y, Sakaguchi M, Mori Y, Saito K, Nakamura T, Bakker EP, Sato Y, Goshima S, Uozumi N (2001). Evidence in support of a four transmembrane-pore-transmembrane topology model for the *Arabidopsis thaliana* Na^+/K^+ translocating AtHKT1 protein, a member of the superfamily of K^+ transporters. Proc Natl Acad Sci USA 98: 6488–6493.

Kaya C, Ak BE, Higgs D (2003). Response of salt-stressed strawberry plants to supplementary calcium nitrate and/or potassium nitrate. J Plant Nutr 26: 543–560.

Kaya C, Higgs D (2003). Supplementary potassium nitrate improves salt tolerance in bell pepper plants. J Plant Nutr 26: 1367–1382.

Kaya C, Kirnak H, Higgs D (2001). Enhancement of growth and normal growth parameters by foliar application of potassium and phosphorus on tomato cultivars grown at high (NaCl) salinity. J Plant Nutr 24: 357–367.

Kyoko I, Hidehiko S, Yasuo N (2004). Developmental course of inflorescence and spikelet in rice. Breeding Sci 54: 147–156.

Leonardi C, Martorana M, Pernice R (2004). Tomato fruit quality in relation to the content of sodium chloride in the nutrient solution. Acta Hortic 659: 769–774.

Li YL, Marcelis LFM, Stanghellini C (2004). Plant water relations as affected by osmotic potential of the nutrient solution and potential transpiration in tomato. J Hortic Sci Biotech 79: 211–218.

Mavrogianopoulos G, Volgi V, Kyritsis S (2002). Use of wastewater as a nutrient solution in a closed gravel hydroponic culture of giant reed (*Arundo donax*). Bioresource Technol 82: 103–107.

Natr L, Lawlor DW (2005). Photosynthetic plant productivity. In: Pessarakli M, editor. Handbook of Photosynthesis. 2nd ed. Boca Raton, FL, USA: CRC Press, pp. 501–524.

Neocleous D, Vasilakakis M (2007). Effect of NaCl stress on red raspberry (*Rubus idoeus* L. Autumn Bliss). Sci Hortic-Amsterdam 112: 282–289.

Niu X, Bressan RA, Hasegawa PM, Pardo JM (1995). Ion homeostasis in NaCl stress environments. Plant Physiol 109: 735–742.

Pettigrew WT (2008). Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiol Plantarum 133: 670–681.

Rodriguez-Navarro A (2000). Potassium transport in fungi and plants. Acta Biochim Biophys 1469: 1–30.

Rubio JS, Garcia-Sanchez F, Rubio F, Martinez V (2009). Yield, blossom-end rot incidence, and fruit quality in pepper plants under moderate salinity are affected by K^+ and Ca^{2+} fertilization. Sci Hortic-Amsterdam 119: 79–87.

Sairam RK, Roa 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.

Sairam RK, Tyagi A (2004). Physiology and molecular biology of salinity stress tolerance in plants. Curr Sci India 86: 407–421.

Savic S, Liu F, Stikic R, Jacobsen SE, Jensen CR, Jovanovic Z (2009). Comparative effects of partial root zone drying and deficit irrigation on growth and physiology of tomato plants. Arch Biol Sci Belgrade 61: 801–810.

Serrano A, Garcia J, Mateos V, Cancillo M, Garrido J (1999). Monthly modes of variation of precipitation over the Iberian Peninsula. J Climate 12: 2894–2919.

Shabala L, Mackay A, Tian Y, Jacobsen SE, Zhou D, Shabala S (2012). Oxidative stress protection and stomatal patterning as components of salinity tolerance mechanism in quinoa (*Chenopodium quinoa* Willd). Physiol Plantarum 146: 26–38.

Shen H, Yu S, Xu Y, Yu R, Jiang W, Chen W (2000). DNA polymorphism of Pvu II site in the lipoprotein lipase gene in patients with type 2 diabetes mellitus. Zhonghua Yi Xue Yi Chuan Xue Za Zhi 17: 24–27.

Shin R, Schachtman DP (2004). Hydrogen peroxide mediates plant root cell response to nutrient deprivation. Proc Natl Acad Sci USA 101: 8827–8832.

Tester N, Davenport R (2003). Na^+ tolerance and Na^+ transport in higher plants. Ann Bot-London 91: 1–25.

Véry AA, Sentenac H (2003). Molecular mechanisms and regulation of K^+ transport in higher plants. Annu Rev Plant Biol 54: 575–603.

Wyn Jones RJ, Pollard A (1983). Proteins, enzymes and inorganic ions. In: Lauchli A, Pirson A, editors. Encyclopedia of Plant Physiology. Berlin, Germany: Springer, pp. 528–562.

Yin X, Vyn TJ (2003). Potassium placement effects on yield and seed composition of no-till soybean seeded in alternate row widths. Agron J 95: 126–132.

Yurtseven E, Kesmez GD, Unlukara A (2005). The effects of water salinity and potassium levels on yield, fruit quality and water consumption of a native central Anatolian tomato species (*Lycopersicon esculantum*). Agr Water Manage 78: 128–135.

Zhu JK (2002). Genetic analysis of plant salt tolerance using *Arabidopsis thaliana*. Plant Physiol 124: 941–948.

Zhu JK (2003). Regulation of ion homeostasis under salt stress. Curr Opin Plant Biol 6: 441–445.