INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES
IJPAES

Volume-4, Issue-3, July-Sept-2014
Copyrights@2014

ISSN 2231-4490
Coden : IJPAES www.ijpaes.com

Received: 14th April-2014 *Revised: 25th April-2014* *Accepted: 4th May-2014*

Research article

IONS CONCENTRATION AND THEIR RATIO IN ROOTS AND SHOOTS OF TOMATO GENOTYPES ASSOCIATED WITH SALINITY TOLERANCE AT EARLY GROWTH STAGE

Magdi A A Mousa[1,2*] , Adel D Al-Qurashi and Ahmed A S Bakhashwain[1]

[1]Department of Arid Land Agriculture, Faculty of Meteorology, Environment and Arid Land Agriculture,
King Abdulaziz University, Jeddah, Saudi Arabia
[2]Department of Horticulture, Faculty of Agriculture, Assiut University, 71526 Assiut, Egypt
* Corresponding Author: E-mail m_a_ahmed@yahoo.com; Tel: 00966544149300

ABSTRACT: In order to identify the significance of Na^+, Ca^+, K^+ and Mg^+ concentration and ratios in plant shoots and roots as indicators for salinity tolerance, growth and biomass of seven wild, cultivated and inbred lines tomato genotypes were evaluated under stresses of saline water. The $NaCl_2$ was used to prepare four treatments of irrigation water salinity,2000ppm (3.12 dsm^{-1}), 4000ppm (6.25 dsm^{-1}), 6000ppm (9.37 dsm^{-1}) and 8000ppm (12.5 dsm^{-1}), while the control treatment was irrigated with tap water. The experiment was conducted in Completely Randomized design (CR) using three replications. The results indicated significant differences between tomato genotypes, irrigation water salinity levels and their interaction at all assessed growth parameters and ions concentration and their ratios in plant shoots and roots. With increasing the salinity levels, a significant reduction was observed in number of leaves/plant and plant fresh and dry weight (g) of all tested tomato genotypes. The reduction of growth parameters observed in ‘LA1421’, ‘KAU I’, ‘KAU II’, ‘F1DOM’ and ‘F1448’ depending on levels of water salinity was found to be less than those of ‘LA2711’ and ‘F1P#P2’ genotypes. Ions accumulation in plant roots and shoots was significantly increased with the increase of salinity levels in irrigation water. The accumulation of Na^+ and Ca^+ in ‘LA1421’, ‘F1448’ and ‘F1DOM’ roots and shoots was extremely higher than that accumulated in ‘LA2711’, ‘KAU I’, ‘KAU II’ and ‘F_1P#P2’. The K^+/Na^+, K^+/Ca^+ and Ca^+/Na^+ values in plant roots and shoots decreased significantly with the increase of salinity stresses except K^+/Ca^+ in ‘KAU I’ shoot and ‘KAU II’ and ‘F_1P#P2’ roots. The tomato genotype ‘KAU I’ and ‘KAU II’ reflected promised genetic stability as it revealed consistent tolerance behavior to the increase of salinity levels in the irrigation water through the less $Na^{+,}$ Ca^+ and Mg^+ and high K/Na in addition to the high number of leaves/plant and dry and fresh weight. The reduction in uptake and accumulation of Na^+ and Ca^+, increasing K^+ uptake, and greater no. of leaves/plant and plant fresh and dry weight are highly recommended as indicators to salinity tolerance in tomato.

Key words: K/Na, Ca/Na, K/Ca, Water salinity, tomato, genetic stability, plant biomass.

INTRODUCTION

Salt stress (water and soil salinity) is limiting the future of agriculture in many areas of the world especially arid and semi-arid regions including Saudi Arabia. The salt-affected soils are the areas that may be saline or sodic and representing 6% of the total world land area. A total of 45 million ha of the total irrigated land area in the world is salt-affected, and there are 32 million ha of dry land agriculture considered to be salt-affected [18]. Plants can be divided into two groups based on their response to salinity stresses. The first group of plants called Glycophytes, including plants sensitive to high salinity. The second group, the Halophytes with plants haveing tolerance behavior to saline soils and water [7, 14]. Salinity causes osmotic stress to plants by altering the water potential in the environment and therefore the plants lose their turgor [28].

Also, high salinity levels results in nutrient deficiency through reducing water uptake from the soil by the plants, and preventing the entry of sufficient amount of the essential minerals for plant growth such as phosphorus, potassium, nitrate, and calcium. Ion cytotoxicity and oxidative stresses are considered to be of important detrimental effect of salinity [28]. Plants under salinity stresses produce smaller and fewer leaves, shorter height and roots and fewer root mass. Because of rising needs to produce salt-tolerant crops, extensive researches have been recognized to improve the salt tolerance of crops by direct selection using the natural genetic variation in stressful environments or by marker-assisted selection. However, commercial success has been very limited due to the physiological and genetic complexity of salt tolerance [7, 14]. Another approach is the generation of transgenic plants [29]. Genetic transformation, gene and genetic mapping and quantities trait loci analysis allowed the development of salt tolerance in plants through better understanding of the physiological and genetical mechanisms of salt tolerance. Molecular marker technology enabled the identification, characterization and comparison of 12 QTLs associated with plant salt tolerance at different developmental stages [6, 9]. There are few screening techniques used as indicators for the identification salinity tolerance in crops. Proline accumulation is considered as one of the most important indicators for plant salinity tolerance. However proline is accumulated also under the stresses of drought, heat tolerance and water defect [3, 22]. The analysis of the K^+ to Na^+ and Ca^+ concentrations and ratios in plant roots and/or shoots are an effective indicator of the plant resistance/tolerance/susceptibility to salinity. Increasing Na^+ and Cl^- causes osmotic stress which reduces water availability to roots and increases probability of ions toxicity for the plant [15]. Tomato cultivars varied significantly in their response to different salinity levels. Increasing NaCl concentrations in nutrient solution adversely affects tomato shoots and roots, plant height, K^+ concentration, and K^+/Na^+ ratio [1, 14]. Growth and yield reductions induced by salinity were attributed to both the osmotic stress and ions toxicity [17]. [14] investigated the effects of irrigation water salinity on growth rate of tomato genotypes at early growth stages. They observed considerable reduction of all tested tomato genotypes with the increase of water salinity levels. Also, among the tested tomato genotypes LA1421 and LA2711 consistent tolerance at all applied salinity levels was shown. The present research was done to study the significance of ions concentration (K^+, Na^+, Ca^+ and Mg^+) and ratios (K^+/Na^+, K^+/Ca^+ and Ca^+/Na^+) in plant roots and shoots as indicators for salinity tolerance of different tomato genotypes irrigated by saline water.

MATERIALS AND METHODS

Plant Materials

Seven tomato genotypes of different genetic backgrounds were studied at early growth stage under different levels of irrigation water salinity. The tomato genotypes were *L. esculentum* cv (KAU I), *L. esculentum* cv (KAU II), *L. esculentum* cv (F1DOM), *L. esculentum* cv (F1448), *L. pennellii* (LA1421), *L. peruvianum* (LA2711) and *L. esculentum* cv (F1P#P2). LA1421 and LA2711 were obtained from the Tomato Genetics Resource Center at UC Davis (TGRC), CA, USA. F1 448 genotype (Syngenta Seeds B.V., Westeunde 62, P.O Box 2, The Netherlands),F1 P.P.#2 and F1 Dom (Petoseed company 2700 Camino del Sol oxand, CA 93030 USA) were collected from seed market of Makkah regions, Saudi Arabia. KAU I and KAU II are F6 breeding lines produced by Department of Arid Land Agriculture, Faculty of Meteorology, Environment & Arid Land Agriculture, King Abdulaziz University Saudi Arabia [14].

Growth condition of tomato plants

This study was conducted in the greenhouse at the Agricultural Research Station at Hada Alsham, King Abdulaziz University from September until December 2012 and repeated from January until May 2013. The experiments were laid out in factorial experiment based on Completely Randomized Design (CR) with 3 replicates. The salt tolerance experiment was carried out in a greenhouse. Tomato seeds were planted in Jiffy 44mm (Jiffy products international AS, Norway) each contained single seed. Twenty five-day-old seedlings at the third-true leaf stage were transferred to plastic post (25 x 25 cm) filled with a mixture of peat moss and vermiculite (1:1 v:v). Drip irrigation system was used to provide the plants with water requirements and the application of salinity stresses.

Salinity stress test

The tomato plants were subjected to salinity stress after 15 days of transplanting (45 days after sowing) at the fives-true-leaves stage. Sodium chloride (NaCl) (HIMEDIA Lab. Lit, India) was used as source for salinity stresses. Four irrigation water salinity treatments, 2000ppm (3.12 dsm^{-1}), 4000ppm (6.25 dsm^{-1}), 6000ppm (9.37 dsm^{-1}) and 8000ppm (12.5 dsm^{-1}) were applied. The control plants were irrigated with tap water. The NaCl treatments were maintained for 30 days.

Growth parameters

At the end of the salinity stress experiment, the plants were carefully removed out the pots and the roots washed under tap water to eliminate the attached soil (Peat moss and vermiculite). The plants were dried on paper tissues for 30 min at room temperature and the following growth and biomass parameters were assessed: no of leaves/plant, plant fresh weight (g) and plant dry weight (g).

Preparation of tomato leaves and roots for nutrient determinations

The fully expanded leaves from the middle part of plants and the plant roots were used for the determination of the total amounts of Na^+, K^+, Ca^+ and Mg^+. The leaves and roots samples were washed carefully in distilled water, and then blotted in filter paper. The leaves and roots samples were dried in a force-air oven at 70 °C for 24 h, ground in a Wiley mill and then used for the analysis of the nutrient concentration. The ground leaves and roots samples (0.5 g) was subjected to sulfuric acid digestion in the presence of H_2O (Wolf, 1982), and diluted with distilled water. Total Na^+, Mg^+, Ca^+ and K^+ contents were directly measured by flame spectrophotometry [13].

Statistical analysis

Analysis of variance (ANOVA) was applied to assess the significance of treatment means. The plant genotypes and salinity stresses and their interactions means were compared using the LSD and Duncan's multiple range test (DMRT). A correlation analysis was also conducted to determine the relations among different variables [10].

RESULTS

There were observed significant differences due to irrigation water salinity levels and tomato genotypes and their interactions on growth and biomass parameters and ions concentration and ration in plant shoots and roots.

Growth and biomass

Growing tomato plants under salinity stresses resulted significant decrease in growth and biomass of the tested genotypes except for the plant dry weight of KAU I. The lowest reduction occurring in the number of leaves due to salinity stresses was observed for KAU II, F1P.#P2, LA1421 and KAU I with an average reduction of -9.1%, -9.37%, -10.43% and -12.56% (compared to control treatment), respectively. With increasing salinity levels plants of LA2711, F1448 and F1DOM produced lower number of leaf by -28.95%, -28.58% and -17.85% compared to unstressed plants, respectively (Table 1). The highest number of leaves was 5.10 and was obtained in KAU I, but LA2711 produced the lowest number of leaves/plant (3.60) and the differences were not statistically significant from that were produced by LA1421 (3.67) and F1P.#P2 (3.70) (Fig 1C). The control treatment (irrigated by normal water) significantly increased number of leaves/plant (5.10), while irrigation water with 4000ppm salinity level produced the lowest number of leaves/plant (3.64) and the differences were not significant from 8000ppm (3.86) (Fig 2C). Plant biomass decreased significantly with the increase in salinity levels. However the reduction percentages were significantly different among the tested tomato genotypes. LA1421 was the most genetically stable genotype under salinity stresses regarding plant fresh weight with an increase of 25.58% and 0.1% at salinity levels 2000ppm and 4000ppm and slightly decrease by -0.05% and -0.02% at 6000ppm and 8000ppm (Table 1). Moderate genetic stability was observed also for the genotypes F1P.#P2, KAU II and KAU I under salinity stresses with average decrease in plant fresh weight of -15.54%, -16.98 and -18.80% compared to control treatment, respectively. On the contrary, F1DOM, F1448 and LA2711 were genetically unstable through the extreme reduction in plant fresh weight under the stresses of high salinity levels. The average reductions in plant fresh weight compared to the control treatment were -45.12%, 32.95% and -30.92% for F1DOM, F1448 and LA2711, respectively (Table 1). The KAU I plants produced the highest fresh weight (47.27), while LA2711 produced the lowest fresh weight (40.52) (Fig 1C). Increasing salinity levels in the irrigation water significantly reduced the fresh weight of tomato plants by -17.03%, -25.35%, -32.28% and -22.69% for 2000ppm, 4000ppm, 6000ppm and 8000ppm, respectively (Fig 2C). The dry weight of KAU I plants increased with the increase of irrigation water salinity levels. The plant dry weight increased by 8.5%, 3.83%, 6.63% and 0.65% under the stresses of water salinity of 2000ppm, 4000ppm, 6000ppm and 8000ppm, respectively (Table 1). Nonsignificant increase in plant dry weight was observed for KAU II, LA1421 and F1P.#P2 under the stresses of 2000ppm and 4000ppm salinity level, but the plant dry weight was dramatically decreased with raising the salinity level to 6000pppm and 8000ppm. A consistent behavior of instability regarding plant dry weight of F1DOM, F1448 and LA2711 under the stress of water salinity was observed. As the salinity increased in the irrigation water, the dry weight of F1DOM, F1448 and LA2711 plants decreased (Table 1). Plants of KAU I produced the highest dry weight (11.2g), while the lowest dry weight was (10.39 g) was produced by LA1421 without significant differences from the other tested genotypes (F1C). The salinity level 2000ppm enhanced plant dry weight with (10.79g), but 8000 ppm reduced plant dry weight (10.44g) (Fig-2C).

Table-1: Growth parameters of seven tomato genotypes grown under different irrigation water salinity levels.

Tomato genotypes	Irrigation water salinity (ppm)	Tomato growth parameters					
		No. leaves/plant	%	Plant fresh weight (g)	%	Plant dry weight(g)	%
KAU1[1]	Control	5.67	0	55.66	0	10.70	0
	2000	5.33	-6.00	49.93	-10.29	11.61	8.50
	4000	5.00	-11.81	45.17	-18.84	11.11	3.83
	6000	5.33	-6.00	43.04	-22.67	11.41	6.63
	8000	4.17	-26.45	42.56	-23.53	10.77	0.65
KAU II[1]	Control	5.00	0	53.81	0	10.54	0
	2000	4.67	-6.60	44.03	-18.17	10.71	1.61
	4000	4.17	-16.6	40.58	-24.58	10.69	1.42
	6000	5.17	3.40	46.90	-12.84	10.03	-4.83
	8000	4.17	-16.60	47.17	-12.34	10.57	0.28
F1 DOM[4]	Control	4.67	0	70.52	0	10.71	0
	2000	4.00	-14.34	43.84	-37.83	10.63	-0.74
	4000	3.17	-32.12	37.17	-47.29	10.62	-0.84
	6000	3.67	-21.41	26.84	-61.94	10.53	-1.68
	8000	4.50	-3.64	46.95	-33.42	10.63	-0.74
F1 448[5]	Control	5.00	0	60.40	0	10.61	0
	2000	3.33	-33.40	47.15	-21.93	10.64	0.28
	4000	3.67	-26.60	40.52	-32.91	10.52	-0.84
	6000	3.33	-33.40	33.70	-44.20	10.49	-1.13
	8000	3.83	-23.40	40.61	-32.76	10.49	-1.13
LA 2711[6]	Control	4.67	0	53.84	0	10.55	0
	2000	4.34	-7.06	40.58	-24.63	10.45	-0.94
	4000	3.00	-35.76	40.55	-24.68	10.32	-2.18
	6000	3.00	-35.76	30.53	-43.29	10.57	0.19
	8000	3.00	-35.76	37.09	-31.11	10.35	-1.89
LA 1421[6]	Control	4.00	0	40.42	0	10.38	0
	2000	4.00	0	50.76	25.58	10.61	2.21
	4000	3.33	-16.75	40.40	-0.05	10.41	0.28
	6000	3.67	-8.25	40.46	0. 10	10.69	2.98
	8000	3.33	-16.75	40.41	-0.02	9.87	-4.91
F1 P.P#2[4]	Control	4.00	0	47.18	0	10.54	0
	2000	3.83	-4.25	40.54	-14.07	10.86	3.03
	4000	3.17	-20.75	40.62	-13.90	10.65	1.04
	6000	3.50	-12.5	37.77	-19.94	10.49	-0.47
	8000	4.00	0	40.44	-14.28	10.40	-1.32
LSD0.05		0.701		12.97		0.050	

[1]=F6 inbred lines produced by Department of Arid Land Agriculture, Faculty of Meteorology, Environment&Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Aribia (Mousa et al, 2013),; [4] =F1 hybrids produced by Petoseed the hybrid vegetable seed company 2700 Camino del Sol oxand, CA 93030 USA; [5]F1 hybrid produced by Syngenta Seeds B.V., Westeunde 62, P.O Box 2, 1600 AA Enkhuizen, The Netherlands; [6]Obtained from the C.M. Rick Tomato Genetics Resource Center Dept. of Plant Sciences (mail stop 3) University of California Davis One Shields Avenue Davis 95616 CA. USA.

Table 2: Plant root contents of K$^+$, Na$^+$, Ca$^+$ and Mg$^+$ of seven tomato genotypes irrigated by saline water as indicators to salinity tolerance at early growing stage.

Tomato genotypes	Irrigation water salinity (ppm)	Ions concentration (mg/kg)							
		K$^+$	%	Ca$^+$	%	Na$^+$	%	Mg$^+$	%
KAU1[1]	Control	0.88	0	1.57	0	0.35	0	0.32	0
	2000	0.61	-30.68	1.68	7.00	0.73	108.57	0.29	-9.375
	4000	0.70	-20.45	1.60	1.91	1.46	317.14	0.38	18.75
	6000	0.94	6.82	1.52	-3.18	1.56	345.71	0.34	6.25
	8000	0.68	-22.73	1.55	-1.27	1.20	242.86	0.29	-9.37
KAU II[1]	Control	0.63	0	1.86	0	0.31	0	0.39	0
	2000	0.63	0	2.68	44.08	4.10	1222.58	0.63	61.54
	4000	1.00	58.73	3.00	61.29	4.11	1225.81	0.73	87.18
	6000	2.98	373.30	2.48	33.33	5.36	1629.03	0.57	46.15
	8000	3.11	393.65	1.88	1.075	0.39	255.81	0.41	5.13
F1 DOM[4]	Control	0.97	0	1.71	0	0.21	0	0.31	0
	2000	0.62	-36.08	4.94	188.89	3.00	1328.57	0.68	119.35
	4000	0.79	-18.56	5.16	201.75	4.13	1866.67	0.75	141.93
	6000	0.71	-26.80	4.37	155.55	3.20	1423.81	0.65	109.67
	8000	0.62	-36.08	5.44	218.12	6.25	2876.19	0.68	119.35
F1 448[5]	Control	0.60	0	1.91	0	0.27	0	0.36	0
	2000	0.71	18.33	5.14	169.11	2.83	948.15	0.71	97.22
	4000	0.66	10.00	6.32	230.89	5.65	1992.59	1.11	208.33
	6000	0.72	20.00	5.46	185.86	4.64	1618.52	1.05	191.67
	8000	0.69	15.00	4.49	135.08	3.60	1233.33	0.81	125.00
LA 2711[6]	Control	0.62	0	1.74	0	0.28	0	0.32	0
	2000	1.29	108.06	5.53	217.82	3.76	1242.86	1.02	218.75
	4000	0.62	0	4.81	176.44	3.15	1025.00	0.92	187.5
	6000	0.67	8.06	4.26	144.83	3.28	1071.43	0.94	193.75
	8000	0.59	-4.84	4.51	159.19	2.68	857.14	0.64	100.00
LA 1421[6]	Control	0.57	0	1.71	0	0.31	0	0.32	0
	2000	0.56	-1.75	1.56	-8.77	0.64	106.45	0.23	-28.12
	4000	0.68	19.30	4.69	174.27	2.77	793.55	0.62	93.75
	6000	0.76	33.33	4.39	156.72	3.22	938.71	0.68	112.50
	8000	0.65	14.03	4.78	179.53	2.56	725.81	0.57	78.12
F1 P.P#2[4]	Control	0.79	0	1.58	0	0.35	0	0.32	0
	2000	0.52	-34.18	1.38	-12.66	0.63	80.00	0.29	-9.37
	4000	1.03	30.38	1.56	-1.26	2.20	528.57	1.03	221.87
	6000	0.90	13.92	1.35	-14.56	1.61	360.00	0.90	181.25
	8000	0.78	-1.26	1.41	-10.76	1.22	248.57	0.79	146.87
LSD0.05		0.230		0.458		0.589		0.089	

[1]=F6 inbred lines produced by Department of Arid Land Agriculture, Faculty of Meteorology, Environment & Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Aribia [14]; [4] =F1 hybrids produced by Petoseed the hybrid vegetable seed company 2700 Camino del Sol oxand, CA 93030 USA; [5]F1 hybrid produced by Syngenta Seeds B.V., Westeunde 62, P.O Box 2, 1600 AA Enkhuizen, The Netherlands; [6]Obtained from the C.M. Rick Tomato Genetics Resource Center Dept. of Plant Sciences (mail stop 3) University of California Davis One Shields Avenue Davis 95616 CA. USA.

Ions concentration in plant roots and shoots

Potassium concentration

Salinity increased the accumulation of K^+, Na^+, Ca^+ and Mg^+ in tomato roots and shoots. The plants root of KAU II accumulated the highest potassium concentration (1.67mg/kg) followed by F1P.#P2 (0.80mg/kg) and KAU I and LA2711 (0.76mg/kg), but roots of the LA1421 plants attained the lowest potassium concentration (Fig 1A). Potassium was increased by 8.33%, 52.78% and 41.67% in plant roots at salinity levels 4000ppm, 6000ppm and 8000ppm as compared with nonsalinized treatments, respectively (Fig 2A). Potassium accumulation in the roots of KAU II plants was markedly increased by 58.73%, 373.30 and 393.65% at salinity levels 4000ppm, 6000ppm and 8000ppm as compared to control treatments, respectively (Table 2). Slight increase in potassium uptake by plant roots of F1448, LA1421 and LA2711was observed with the increase of salinity, whereas potassium uptake was decreased for KAU I, F1DOM and F1P.#P2 (Table 2). Potassium concentration in roots was lower than in shoots regardless of the salinity levels. The tested tomato genotypes accumulated more potassium in their shoots under high salinity levels compared to control treatments except for KAU II and F1P.#P2. The obvious concentration of potassium was accumulated by KAU I plants at water salinity 4000ppm (3.40mg/kg) with an increase of 51.11% as compared with nonsalinized treatment (Table 3). Comparing with control treatment, salinity increased potassium concentration in plant shoots by 19.03%, 4.86% and 2.02% at water salinity 4000ppm, 6000ppm and 8000ppm, respectively (Fig 2B). Plants of KAU I and LA1421 accumulated higher potassium in their shoots than in other tested genotypes, and the lowest potassium accumulation was observed when analyzing plant shoots of LA2711 (Fig 1B).

Calcium concentration

Calcium uptake by plants root was significantly affected by the applied salinity levels and the tested tomato genotypes. As salinity increased the calcium uptake by plant roots increased for all tested tomato genotypes expect for KAU I (at 6000ppm and 8000ppm) and F1P.#P2 (at all applied salinity levels). The roots of KAU I and F1P.#P2 plant absorbed lower calcium under higher salinity than the unstressed plants (Table 2). Among the higher calcium accumulation genotypes, F1448 roots absorbed the highest amount of calcium at all salinity levels followed by F1DOM and LA2711 (Fig 1A). Calcium uptake was increased as salinity levels increased with strikingly increase at salinity level 6000ppm (3.87 mg/kg as compared with 1.73 mg/kg for unstressed plants) (Fig 2A). The behavior of calcium accumulation in plant shoots slightly differed from those in plant roots. KAU I, KAU II and F1P.#P2 plants shoot attained lower amount of calcium than unstressed plants at all applied water salinity treatments. Consistent increase in calcium accumulation in plant shoots of F1DOM, F1448, LA2411and LA2711 under high salinity levels was observed (Table 3). Plant shoots of F1DOM accumulated 5.21mg/kg followed by than those accumulated by F1448 (4.72mg/kg), LA1421 (4.64mg/kg), KAU II (1.74mg/kg), KAU I (1.80mg/kg), F1P.#P2 (1.87mg/kg) (Fig 1B). Plants shoots of the nonsalinized treatments contained the lowest calcium (1.98 mg/kg), while the salinity level 8000ppm caused the highest calcium accumulation (4.35mg./kg) (Fig 2A).

Sodium concentration

As compared to unstressed plants sodium absorbance increased by 646.67%, 1016.67%, 986.67% and 753.93% in plant roots and 1030.55%, 1638.89%, 1475.00% and 2244.44% in plant shoots at water salinity 2000ppm, 4000ppm, 6000ppm and 8000ppm, respectively (Figures 2A and 2B). Plant roots of the tomato genotype F1448 and F1DOM and plant shoots of LA1421 and F1DOM accumulated higher Na^+ than other tested genotypes, while the lowest sodium concentration was observed in KAU I and F1P.#P2 roots and shoots and KAU II shoots(Fig 1A&B). Significant interaction between tomato genotypes and salinity levels regarding sodium concentration in plant roots and shoots was observed. Sodium increased in plant roots and shoots of F1DOM, F1448, LA1421 and LA2711 with the increase in salinity levels and the sodium accumulation in shoots was strikingly higher than in roots. Slight increase in sodium uptake measured in KAU I, KAU II and F1P.#P2 roots at the higher water salinity levels (Table 2). The highest sodium concentrations in plant shoots were 15.86mg/kg and 14.86mg/kg and measured in LA1421 and F1DOM at salinity levels 8000ppm (Table 3).

Table-3: Plant shoots Contents of K$^+$, Na$^+$, Ca$^+$ and Mg$^+$ of seven tomato genotypes irrigated by saline water as indicators to salinity tolerance at early growing stage.

Tomato genotypes	**Irrigation water salinity (ppm)**	**Ions concentration (mg/kg)**							
		K$^+$	**%**	**Ca$^+$**	**%**	**Na$^+$**	**%**	**Mg$^+$**	**%**
KAU1[1]	Control	2.25	0	2.11	0	0.28	0	0.53	0
	2000	3.05	35.55	1.80	-14.70	1.49	432.14	0.49	-7.55
	4000	3.14	39.55	1.59	-24.64	1.84	557.14	0.42	-20.75
	6000	3.4	51.11	1.76	-16.59	2.83	910.71	0.43	-18.87
	8000	2.71	20.44	1.96	-7.11	3.51	1153.57	0.49	-7.55
KAU II[1]	Control	2.50	0	1.93	0	0.32	0	0.52	0
	2000	3.17	26.80	2.35	21.76	5.09	1490.62	0.54	3.85
	4000	3.11	24.40	1.37	-29.01	1.32	312.50	0.22	-57.69
	6000	1.13	-54.80	1.46	-24.35	1.34	318.75	0.29	-44.23
	8000	1.03	-58.80	1.72	-10.88	1.61	403.12	0.32	-38.46
F1 DOM[4]	Control	2.47	0	2.8	0	0.52	0	0.53	0
	2000	2.59	4.86	5.22	86.43	6.09	1071.15	1.07	101.88
	4000	3.02	22.26	6.49	131.78	11.74	2157.69	1.20	126.41
	6000	2.74	10.93	5.72	104.28	9.60	1746.15	1.11	109.43
	8000	3.02	22.27	6.54	133.57	14.86	2757.69	1.19	124.53
F1 448[5]	Control	2.52	0	1.95	0	0.25	0	0.42	0
	2000	2.45	-2.78	5.09	161.02	5.57	2128.00	0.93	121.43
	4000	2.83	12.30	4.91	151.79	7.87	3048.00	1.06	152.38
	6000	2.81	11.51	5.08	160.51	7.26	2804.00	1.00	138.09
	8000	3.26	29.36	6.58	237.43	11.73	4592.00	1.22	190.47
LA 2711[6]	Control	1.95	0	1.86	0	0.25	0	0.42	0
	2000	1.53	-21.54	5.40	190.32	4.68	1772.00	0.96	128.57
	4000	2.35	20.51	4.91	163.97	5.52	2108.00	0.86	104.76
	6000	2.17	11.28	3.87	108.06	5.22	1988.00	0.88	109.52
	8000	2.36	21.02	5.46	193.54	8.70	3380.00	1.00	138.09
LA 1421[6]	Control	2.81	0	1.99	0	0.43	0	0.39	0
	2000	2.61	-7.12	2.49	25.12	3.89	804.65	0.44	12.82
	4000	2.83	0.71	6.10	206.53	12.83	2883.72	0.82	110.25
	6000	3.21	14.23	6.12	207.53	10.75	2400.00	0.75	92.30
	8000	3.13	11.39	6.52	227.63	15.86	3588.37	0.83	112.82
F1 P.P#2[4]	Control	2.80	0	1.98	0	0.49	0	0.51	0
	2000	2.52	-10.00	2.03	2.52	1.70	246.94	0.51	0
	4000	3.31	18.21	1.89	-4.54	2.70	451.02	0.42	-17.65
	6000	2.66	-5.00	1.76	-11.11	2.71	453.06	0.45	-11.76
	8000	2.16	-22.85	1.71	-13.64	2.81	473.46	0.43	-15.68
LSD0.05		0.458		0.515		1.584		0.089	

[1]=F6 inbred lines produced by Department of Arid Land Agriculture, Faculty of Meteorology, Environment&Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Aribia,; [4] =F1 hybrids produced by Petoseed the hybrid vegetable seed company 2700 Camino del Sol oxand, CA 93030 USA; [5]F1 hybrid produced by Syngenta Seeds B.V., Westeunde 62, P.O Box 2, 1600 AA Enkhuizen, The Netherlands; [6]Obtained from the C.M. Rick Tomato Genetics Resource Center Dept. of Plant Sciences (mail stop 3) University of California Davis One Shields Avenue Davis 95616 CA. USA.

Table-4: Ratios of K^+ / Na^+, Ca^+ / Na^+ and K^+ / Ca^+ in plant roots as indicators for salinity tolerance of seven tomato genotypes irrigated by different water salinity levels at early growing stage.

Tomato genotypes	Irrigation water salinity	Ions Ratio and percentages of increase and decrease from control					
		K^+/Na^+	%	K^+/Ca^+	%	Ca^+/Na^+	%
KAU1[1]	Control	2.51	0	0.56	0	4.48	0
	2000	0.84	-66.53	0.36	-35.71	2.30	-48.66
	4000	0.48	-80.87	0.44	-21.426	1.09	-75.66
	6000	0.60	-76.09	0.62	10.714	0.97	-78.342
	8000	0.57	-77.29	044	-21.42	1.29	-71.20
KAU II[1]	Control	2.03	0	0.34	0	6.00	0
	2000	0.15	-92.61	0.23	-32.35	0.65	-89.17
	4000	0.24	-88.17	0.33	-2.94	0.73	-87.83
	6000	0.55	-72.90	1.20	252.94	0.46	-92.33
	8000	7.97	292.61	1.65	385.29	4.82	-19.67
F1 DOM[4]	Control	4.62	0	0.57	0	8.14	0
	2000	0.21	-95.45	0.12	-78.94	1.65	-79.73
	4000	0.19	-95.88	0.15	-73.68	1.25	-84.64
	6000	0.22	-95.24	0.16	-71.93	1.36	-83.29
	8000	0.09	-98.05	0.11	-80.70	0.87	-89.31
F1 448[5]	Control	2.22	0	0.31	0	7.07	0
	2000	0.25	-88.74	0.14	-54.84	1.82	-74.25
	4000	0.12	-94.60	0.10	-67.74	1.12	-84.15
	6000	0.15	-93.24	0.13	-58.06	1.17	-83.45
	8000	0.19	-91.44	0.15	-51.61	1.25	-82.31
LA 2711[6]	Control	2.21	0	0.36	0	6.21	0
	2000	0.34	-84.61	0.23	-36.11	1.47	-76.32
	4000	0.19	-91.40	0.13	-63.90	1.53	-75.36
	6000	0.20	-90.95	0.16	-55.55	1.30	-79.06
	8000	0.22	-90.04	0.13	-63.89	1.68	-72.94
LA 1421[6]	Control	1.84	0	0.33	0	5.52	0
	2000	0.87	-52.72	0.36	9.09	2.44	-55.79
	4000	0.24	-86.95	0.14	-57.57	1.69	-69.38
	6000	0.24	-86.95	0.17	-48.48	1.36	-75.36
	8000	0.25	-86.41	0.13	-60.61	1.87	-66.12
F1 P.P#2[4]	Control	2.26	0	0.50	0	4.51	0
	2000	0.82	-63.72	0.38	-24.00	2.19	-51.44
	4000	0.47	-79.20	0.66	32.00	0.71	-84.25
	6000	0.56	-75.22	0.67	34.00	0.83	-81.59
	8000	0.64	-71.68	0.55	10.00	1.16	-74.27
LSD0.05		0.474		0.089		0.527	

[1]=F6 inbred lines produced by Department of Arid Land Agriculture, Faculty of Meteorology, Environment&Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Aribia,; [4]=F1 hybrids produced by Petoseed the hybrid vegetable seed company 2700 Camino del Sol oxand, CA 93030 USA; [5]F1 hybrid produced by Syngenta Seeds B.V., Westeunde 62, P.O Box 2, 1600 AA Enkhuizen, The Netherlands; [6]Obtained from the C.M. Rick Tomato Genetics Resource Center Dept. of Plant Sciences (mail stop 3) University of California Davis One Shields Avenue Davis 95616 CA. USA.

Magnesium concentration

A consistent increase in magnesium in plant roots and shoots of F1DOM, F1448 and LA2711under higher water salinity was observed (Table 2 and 3). Salinity increased magnesium uptake by plant roots and shoots) for all tested tomato genotypes except for KAU I roots and KAU I, KAU II and F1P.#P2 shoots. The F1448 roots and F1DOM shoots registered the highest magnesium concentration with 0.81mg/kg and 1.02mg/kg, respectively. With 0.32mg/kg and 0.34mg/kg the genotypes KAU I and KAU II accumulated the lowest magnesium in their roots and shoots (Figures 1A&B). Plant roots at salinity levels 4000ppm and plant shoots at salinity level 8000ppm absorbed highest concentration. Plant roots and shoots of the nonsalinized plants absorbed the lowest Mg^+ concentration with 0.32mg/kg and 0.47mg/kg, respectively (Fig 2A).

Ions ratio in plant roots and shoots

K^+/Na^+ ratio

As salinity levels increased K^+/Na^+ ratio markedly decreased in roots of tomato at all applied salinity levels except for 8000ppm. Roots and shoots of the nonosalinized tomato plants produced the highest K^+/Na^+ ratio with 2.26 and 7.32. Among the applied water salinity levels, 8000ppm enhanced K/Na ratio in plant roots (1.43), whereas 4000ppm significantly decreased the K^+/Na^+ ratio (0.28) (Fig 2D). Among the tomato genotypes, plants roots of KAU II absorbed higher K^+ than Na^+ with ratio of 2.22. Nevertheless, F1448, LA2711 and LA1421 absorbed more Na^+ than K^+ with ratios of 0.59, 0.64 and 0.69 with no significant differences, respectively (Fig 1D). As compared to nonsalinized plants, extreme reduction in $K^+:Na^+$ ratio in plant roots of F1DOM at the higher salinity levels (average reduction of -96.15%) followed by F1448 (-92.00%) and LA2711 (89.25%) (Table 4). Moderate reduction and partially balanced ratio of $K^+:Na^+$ was observed in plant roots of F1P.#P2, KAU I, KAU II and LA1421 under all applied salinity levels (Table 4). On the other hand, lower K^+/Na^+ ratio in plant shoots was observed at salinity 8000ppm (0.46). The water salinity 6000ppm produced the highest K^+/Na^+ ratio with 0.64, while balanced K^+/Na^+ was observed for the salinity levels 2000ppm and 4000ppm (Fig 2E). Extreme increase in K^+/Na^+ ratio was observed in shoots of KAU I (2.79) followed by KAU II (2.48), F1448 (2.34) and F1P.#P2 (2.05). Shoots of F1DOM exhausted the lowest K/Na ration (1.20) followed by LA1421 (1.61) and LA2711 (1.88) (Fig 1E). Increasing water salinity significantly decreased K/Na ratios in plant shoots of LA2711, F1DOM and LA1421 with average reduction of -95.35%, -94.66% and -93.83% as compared to nonsalinized treatments, respectively. Moderate reduction in K^+/Na^+ ratio was observed in plant shoots of KAU II, F1P.#P2 and KAU I at high level of water salinity (Table 5).

K^+/Ca^+ ratio

Plants roots of KAU II accumulated the highest ratio of K^+/Ca^+ (0.76), while F1448 with 0.22 produced the lowest K^+/Ca^+ ratio (Fig 1D). Water salinity levels 6000ppm and 8000ppm partially resulting balanced K^+/Ca^+ ratios (0.45) in plant roots, however K/Na ratio significantly reduced at the lower salinity levels (0.26 for 2000ppm and 40.28 for 4000ppm) (Fig 2D). As compared to nonslaonized treatments, the K^+/Ca^+ ratio in plant roots of the tested tomato genotypes significantly decreased as salinity levels increased except KAU I at 6000ppm (0.62 compared to 0.56 for control), KAU II at 6000ppm and 8000ppm (1.20 and 1.65 compared to 0.34 for control), LA1421 at 2000ppm (0.36 compared to 0.33 for control) and F1P.#P2 at 4000ppm, 6000ppm and 8000ppm (0.66, 0.67 and 0.55 compared to 0.50 for control) (Table 4). Regarding K^+/Na^+ ratio in tomato shoots, the results indicated that nonsalinized plants accumulated higher potassium and lower calcium with K^+/Ca^+ ratio of 1.24. Among the tested salinity levels, 4000ppm increased K^+/Ca^+ ratio (1.14), whereas 8000ppm significantly decreased K^+/Ca^+ ratio (0.73) (Fig 2E). Furthermore, KAU I shoots significantly attained higher K/Ca ratio than other tested genotype (1.62) followed by F1P.#P2 (1.44) and KAU II (1.26). Lower K/Ca ratio was found in LA2711 shoots (0.56) (Fig 1E). The interaction between tomato genotypes and water salinity levels indicated that, as salinity increases the ratio of K^+/Ca^+ in plants shoots was considerably decreased of the tested tomato genotypes. The only exceptions were for KAU I at 2000pppm, 4000ppm, 6000ppm and 8000ppm (1.69, 1.97, 1.93 and 1.38 compared to 1.06 for control), KAU II at 2000ppm and 4000ppm (1.35 and 2.27 compared to 1.29 for control) and F1P.#P2 at 4000ppm and 6000ppm (1.75 and 1.52 compared to 1.41 for control) (Table 5).

Table-5: Ratios of K^+/Na^+, Ca^+/Na^+ and K^+/Ca^+ in plant shoots as indicators for salinity tolerance of seven tomato genotypes irrigated by different water salinity levels at early growing stage in plant shoots.

Tomato genotypes	Irrigation water salinity (ppm)	Ions Ratio and percentages of increase and decrease from control					
		K^+/Na^+	%	K^+/Ca^+	%	Ca^+/Na^+	%
KAU1[1]	Control	8.04	0	1.06	0	7.53	0
	2000	2.05	-74.50	1.69	59.43	1.21	-83.9
	4000	1.71	-78.73	1.97	85.85	0.86	-88.58
	6000	1.20	-85.07	1.93	82.07	0.62	-91.76
	8000	0.78	-90.33	1.38	30.18	0.56	-92.56
KAU II[1]	Control	7.81	0	1.29	0	6.03	0
	2000	0.63	-91.93	1.35	4.65	0.46	-92.37
	4000	2.35	-69.91	2.27	75.97	1.04	-82.75
	6000	0.88	-88.73	0.78	-39.53	1.09	-81.92
	8000	7.81	0	0.60	-53.48	1.07	-82.25
F1 DOM[4]	Control	4.75	0	0.88	0	5.38	0
	2000	0.43	-90.94	0.50	-43.18	0.86	-84.01
	4000	0.26	-94.52	0.46	-47.73	0.55	-89.78
	6000	0.28	-94.10	0.48	-45.45	0.59	-89.03
	8000	0.20	-95.79	0.46	-47.73	0.44	-91.82
F1 448[5]	Control	10.08	0	1.29	0	7.80	0
	2000	0.44	-95.63	0.48	-62.79	0.91	-88.33
	4000	0.36	-96.43	0.57	-55.81	0.62	-92.05
	6000	0.38	-96.23	0.55	-57.36	0.70	-91.02
	8000	0.28	-97.22	0.50	-61.24	0.56	-92.82
LA 2711[6]	Control	7.80	0	1.05	0	7.44	0
	2000	0.33	-95.77	0.28	-73.33	1.15	-84.54
	4000	0.43	-94.48	0.48	-54.28	0.90	-87.90
	6000	0.42	-94.61	0.56	-46.67	0.74	-90.05
	8000	0.27	-96.54	0.43	-59.05	0.63	-91.53
LA 1421[6]	Control	6.53	0	1.41	0	4.63	0
	2000	0.67	-89.74	1.04	-26.24	0.64	-86.18
	4000	0.23	-96.48	0.46	-67.37	0.47	-89.85
	6000	0.30	-95.40	0.52	-63.12	0.56	-87.90
	8000	0.20	-96.94	0.48	-65.96	0.41	-91.14
F1 P.P#2[4]	Control	5.71	0	1.41	0	4.04	0
	2000	1.48	-74.08	1.24	-12.05	1.19	-70.54
	4000	1.22	-78.63	1.75	24.11	0.70	-82.67
	6000	0.98	-82.83	1.51	7.09	0.65	-83.91
	8000	0.77	-86.51	1.26	-10.63	0.61	-84.90
LSD0.05		0.532		0.207		0.343	

[1]=F6 inbred lines produced by Department of Arid Land Agriculture, Faculty of Meteorology, Environment&Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Aribia(Mousa et al, 2013); [4] =F1 hybrids produced by Petoseed the hybrid vegetable seed company 2700 Camino del Sol oxand, CA 93030 USA; [5]F1 hybrid produced by Syngenta Seeds B.V., Westeunde 62, P.O Box 2, 1600 AA Enkhuizen, The Netherlands; [6]Obtained from the C.M. Rick Tomato Genetics Resource Center Dept. of Plant Sciences (mail stop 3) University of California Davis One Shields Avenue Davis 95616 CA. USA.

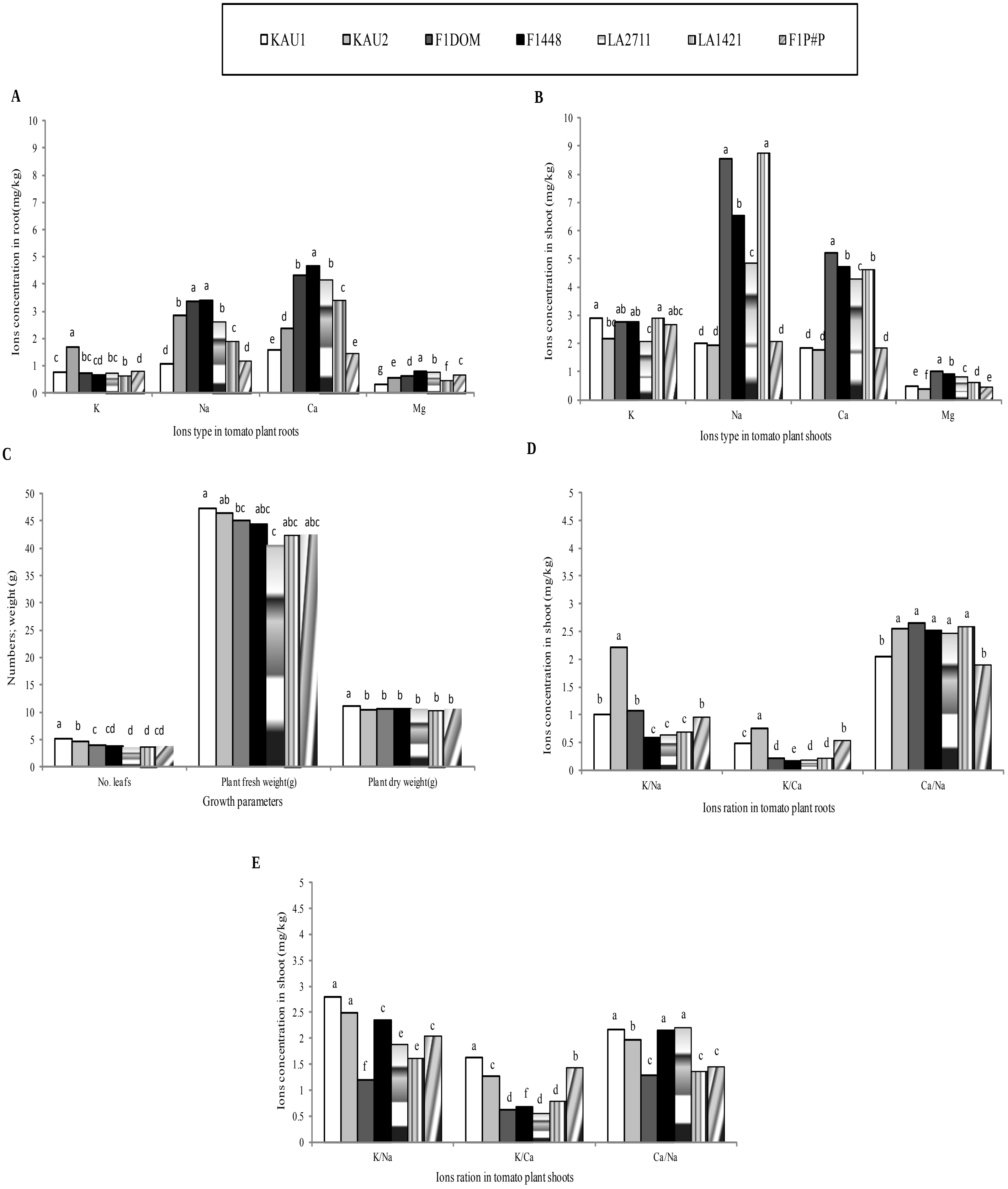

Fig-1. Genotypic effects on tomato growth parameters and ions concentration and ration in plant shoots and roots under irrigation water salinity stresses: A) Ions concentration in plant roots, B) Ions concentration in plant shoots, D) growth parameters, Ions ration in plant roots and E) ions ration in plant shoots.

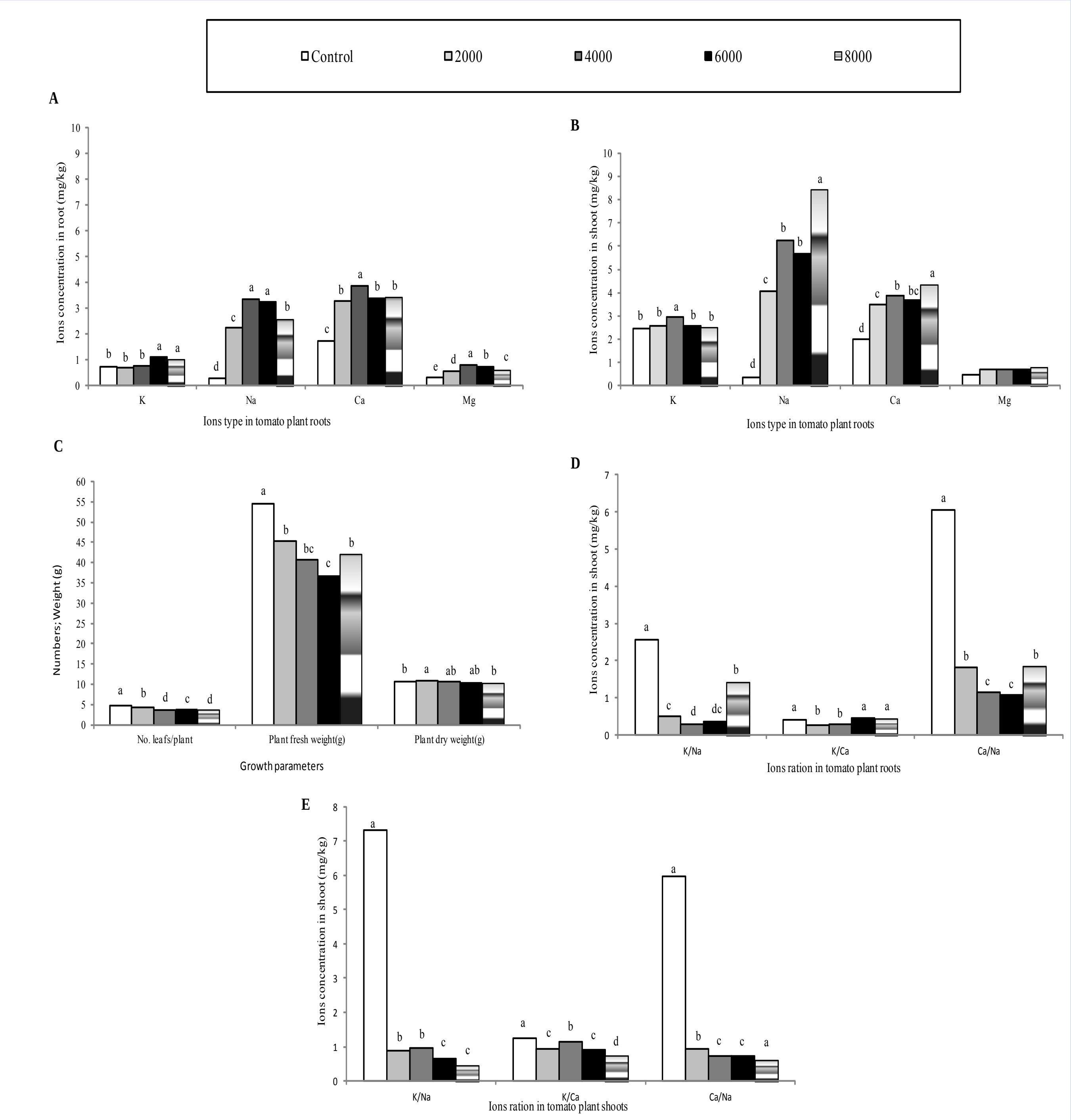

Fig-2. Mean values of growth parameters and ions concentration and ration in plant shoots and roots as affected by different levels of irrigation water salinity: A) Ions concentration in plant roots, B) Ions concentration in plant shoots, D) growth parameters, Ions ration in plant roots and E) ions ration in plant shoots.

Ca^+/Na^+ ratio

High Ca^+/Na^+ ratio was observed in plants roots of F1DOM (2.66), LA2411 (2.59), KAU I (2.55), F1448 (2.52), LA2711 (2.48) and KAU II (2.04), while roots of F1P.#P2 plants attained the lowest Ca^+/Na^+ ratio (1.90) (Fig 1D). Moreover, plants shoots of LA2711 constituted the highest Ca^+/Na^+ ratio (2.21), followed by KAU I (2.17) and F1448 (2.14), whereas plant shoots of F1DOM accumulated the lowest Ca+/Na+ ratio (1.29) followed by LA1421 (1.37) and F1P.#P2 (1.45) (Fig 1E).

Regarding water salinity levels, the unstressed tomato plants absorbed the highest Ca+/Na+ ratio in roots (6.04) and shoots (5.98). Also, high ratio of Ca+/Na+ was observed in plants roots at salinity levels 8000ppm and 2000ppm, while 4000ppm and 6000 pppm registered the lowest Ca+/Na+ ratio (Table 4 and Fig 1E). Likewise, Ca+/Na+ ratio in plant shoots was significantly increased at salinity level 2000ppm, but insignificant reduction was observed at salinity levels 4000ppm (0.74), 6000ppm (0.72) and 8000ppm (0.62) (Table 5 fig 2E). Regarding interaction between salinity levels and genotypes, the tested tomato genotypes significantly constituted lower Ca+/Na+ ratios in their roots and shoots at all applied salinity levels as compared to unstressed treatments (Table 4&5).

Table 6. Efficiency of using plant growth, biomass and ions accumulation and ratios in plant roots and shoots as indicators for salinity tolerance of tomato genotypes irrigated by different levels of saline water.

Tomato genotypes	No. leafs /plant	PFW	PDW	Ions concentration (mg/kg)								Ions ratio					
				K		Ca		Na		Mg		K/Na		K/Ca		Ca/Na	
				Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
Genotypes suggested to follow the 'Ions selectivity' (excluders) mechanism to salinity tolerance																	
KAU I	4.96a	45.20a	11.22a	0.76bc	2.91a	1.58e	1.84d	1.06d	1.99d	0.32g	0.47e	1.01b	2.79a	0.49c	1.62a	2.04b	2.17a
KAU II	4.54b	44.67ab	10.50b	1.67a	2.18c	2.37d	1.76d	2.85b	1.93d	0.55e	0.37f	2.22a	2.48ba	0.76a	1.26c	2.55a	1.96b
Genotypes suggested to follow the 'Ions accumulation' (includers) mechanism to salinity tolerance																	
LA1421	3.58d	43.01abc	10.39b	0.64d	2.92a	3.42c	4.64b	1.90c	8.75a	0.48f	0.64d	0.69c	1.61e	0.23d	0.79d	2.59a	1.37c
F1DOM	3.83.00c	38.70abc	10.60b	0.74bc	2.77ab	4.32b	5.21a	3.36a	8.56a	0.61d	1.02a	1.08b	1.20f	0.22d	0.62d	2.66a	1.29c
F1448	3.54cd	40.49abc	10.53b	0.67cd	2.77ab	4.66a	4.74b	3.40a	6.53b	0.81a	0.92b	0.59c	2.34bc	0.17e	0.68ef	2.52a	2.14a
Expected susceptible genotypes to salinity stresses																	
F1P.#P2	3.62cd	39.84abc	10.60b	0.80b	2.69abc	1.45e	1.87d	1.20b	2.08d	0.67c	0.46e	0.96b	2.04dc	0.55b	1.44b	1.90b	1.45c
LA2711	3.33d	37.18c	10.42b	0.76bc	2.07c	4.17b	4.30c	2.63b	4.87c	0.77b	0.82c	0.64c	1.88de	0.20ed	0.56ef	2.48a	2.21a

DISCUSSION

Ion selectivity and ion accumulation were reported to be the most important methods for understanding salt tolerance mechanisms in plant (Noble et al., 1984; Sykes, 1985, Tal and Shannon, 1983). Ion selectivity mechanism includes limitation of toxicions uptake and keeping normal range of nutrition. These plants could be more salt tolerant than those that do not restrict ion accumulation and lose nutrient balance [26]. The term 'includers" was used to distinguish these plant species [12, 20]. Ion accumulation occurred in some plant species that take up high concentration of ions for osmotic adjustment. The physiological mechanisms of this technique based on sequestering the salt away from metabolic sites and synthesize of compatible solutes for osmotic balance [7]. The term of "includers" was used to discriminate these plant species [20]. In our study the tomato genotypes 'KAU I' and 'KAU II' (excluders plant) presented the lowest concentration of Na$^+$, Ca$^+$ and Mg$^+$ in their roots and shoots. Therefore, these genotypes can be classified to follow the ion selectivity mechanism with regards to their response to salinity. By contrast the highest concentration of Na$^+$, Ca$^+$ and Mg$^+$ in plant roots and shoots were registered for 'F1DOM', 'LA1421' and 'F1448' (includers plant).These genotypes were suggested to follow the ions accumulation mechanism in their responses to salinity (Table 6). Under saline conditions ionic imbalance, nutrient-deficiency and ions toxicity can occur due to the increase of Na$^+$ accumulation in plants. For instance, it was reported that plant growth was depressed at higher Na$^+$ concentrations due to the decreased uptake of K$^+$, Ca^{2+} and Mg^{2+} [12, 14]. However, salt tolerance in tomato can be enhanced by increasing the ratio of K:Na, accumulation more K$^+$ and decrease the Na$^+$ accumulation in plant shoots [5, 12]. As presented in Table 6, the tomato genotypes can be classified into three categories. First, the inbred lines 'KAU I' and 'KAU II' able to limit Na$^+$, Ca$^+$ and Mg$^+$ accumulation and offering higher K$^+$ concentration and higher K:Na, K:Ca and Ca:Na ratios in plant shoots and roots.

Second, genotypes were competent to accumulate higher Na$^+$ and Ca$^+$ (LA1421, F1448 and F1DOM) showing high K$^+$ concentration, low K:Na, K:Ca and Ca:Na. The genotypes of first and second categories are considered as salinity tolerant. Third, the genotypes 'LA2711' and F1P.#P2: registering lower K$^+$, Na$^+$, Ca$^+$ and Mg$^+$ concentrations and lower ratios of K:Na, K:Ca and Ca:Na. These genotypes can count as susceptible to salinity stresses. It was reported that plant biomass (fresh and dry weight of whole plant or plant leaves, roots and shoots) and yield are of the most widely used indices to identify abiotic stress tolerance including salinity [3, 4, 21, 23]. As salinity increases the accumulation of Na$^+$ and Cl$^-$ in plant shoots and roots increases resulting in inhibition of plant growth and development [12, 18]. In our study, the genotypes 'KAU I' and 'KAU II' presented the highest biomass production values (45.20g and 11.22g and 44.67g and 10.50g of plant fresh and dry weight for 'KAU I' and 'KAU II', respectively), which can be attributed to the lower accumulation of Na$^+$ and higher K$^+$ concentration in their shoots.

These results indicate that 'KAU I' and 'KAU II' were more tolerant to salinity than other genotypes. An inverse correlation was found between the K^+ deficiency of salinity stressed plants and accumulation of Na^+, indicating the existence of competition effects between Na^+ and K^+ ions. This competent behavior of both ions may be attributed to same transport system at the root surface of Na^+ and K^+ which was contradicted by the findings of the present study. We observed that the genotypes 'LA1421', 'F1DOM' and 'F1448' accumulated high concentration of Na^+, Ca^+ and K^+, but a reduction was observed in plant growth (no. of leaves/plant) and biomass (plant fresh and dry weight) as compared to 'KAU I' and 'KAU II'. These genotypes can be presented as salt tolerance based on the hypothesis of 'ions accumulation mechanism'. On the contrary, the lowest production of plant biomass was found in LA2711 and F1P.#P2, defining them as the most salt-sensitive of all tested genotypes (Table 6). Plants of these genotypes showed considerable reduction in fresh and dry weight even with low concentration of Na^+ due to their lower capacity to accumulate high K^+ concentration in their shoots. The K:Na ratio, due to its strong relationship with plant growth and biomass production, was used as an indicator to salinity tolerance by many authors [2, 23, 12, 15, 4, 21]. Accordingly, in the present work, the K:Na was found to be an efficient consistent indicator of salt tolerance (Table 6). Further investigations are required to understand the roles of Ca^+ and Mg^+ and their ratios with K^+ and Na^+ in salt tolerance/susceptible of the tested tomato genotypes.

CONCLUSION

In the present study, we present the tomato inbred lines 'KAU I' and 'KAU II' as a new source for salinity tolerance following the mechanism of 'ions selectivity'. Three other tested genotypes 'LA1421', 'F1DOM' and 'F1448' can be considered as salinity tolerance on the basis of 'ion accumulation' mechanism. We highly recommend the use of certain nutritional indicators for salt tolerance in tomato, such as the reduction in uptake and accumulation of Na+ and Ca, increasing K+ uptake, and greater no. of leaves/plant and plant fresh and dry weight.

ACKNOWLEDGEMENT

This project was funded by the Deanship of Scientific Research (DSR), King Abdulaziz University, Jeddah, under grant No (229/155/1432). The authors, therefore, acknowledge with thanks DSR technical and financial support.

REFERENCES

[1] Al-Karaki, G.N. 2000. Growth, water use efficiency, and sodium and potassium acquisition by tomato cultivars grown under salt stress. J.Plant Nutr. 23: 1-8.

[2] 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.

[3] Ashraf, M., McNeilly, T. 2004. Salinity tolerance in Brassica oilseeds. Crit. Rev. Plant Sci. 23, 157–174.

[4] Babu, M. A., Singh, D. and Gothandam, K. M. 2012. The effect of salinity on Growth, hormones and mineral elements in leaf and fruit of tomato cultivar PKM1. The Journal of Animal & Plant Sciences, 22(1): 159-164.

[5] Dasgan, H.Y., Aktas, H., Abak, K., Cakmak, I. 2002. Determination of screening techniques to salinity tolerance in tomatoes and investigation of genotype responses. Plant Sci. 163, 695–703.

[6] Ellis, R.P., Forster, B.P., Waugh, R., Handley, L.L., Robinson, D., Gordon, D.C. and Powell, W. 1997. Mapping physiological traits in barley. New Phytol. 137: 19–157

[7] Flowers, T.J. 2004. Improving crop salt tolerance. Journal of Experimental Botany 55, 307–319.

[8] Flowers, T., Troke, P. F., and Yeo, A. R. 1977. The mechanism of salt tolerance in halophytes. Ann.Rev. Plant Physiol. 28**:**89–121.

[9] Foolad, M. R..2004. Recent advances in genetics of salt tolerance in tomato. Review of Plant Biotechnology and Applied Genetics. 76**:** 101–119.

[10] Gomez, K. A. and Gomez, A. A. 1984. Statistical Procedures for Agricultural Research. 2nd edn. John Wiley and Sons, New York, 680

[11] Holger, B., Peterka, H., Mousa M. A. A., Ding, Y., Zhang,S. and Li, J. 2009. Molecular mapping in oil radish (Raphanus sativus L.) and QTL analysis of resistance against beet cyst nematode (Heterodera schachtii). Theor Appl Genet, 118: 775-782.

[12] Juan, M., Rivero, R M., Romero, L, Ruizet, J M. 2005. Evaluation of some nutritional and biochemical indicators in selecting salt-resistant tomato cultivars Environmental and Experimental Botany 54:193–201.

[13] Lachica, M., Aguilar, A., Ya˜nez, J., 1973. An´alisis foliar. M´etodos utilizados en la Estaci´on Experimental del Zaidin. Anal. Edad. Agrobiol. 32, 1033–1047.

[14] Mousa M A. A., Al-Qurashi A D. and Bakhashwain A A. S. 2013. Response of tomato genotypes at early growing stages to irrigation water salinity. Journal of Food, Agriculture & Environment 11 (2): 501-507.

[15] Maggio A., Raimondi, G., Martino, A., De Pascale, S.2007. Salt stress response in tomato beyond the salinity tolerance threshold. Environmental and Experimental Botany 59 (2007) 276–282.

[16] 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

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

[18] Munns, R., Husain, S., Rivelli, A.R., James, R.A., Condon TonyA.G., Lindsay, M.P., Lagudah, E.S., Schachtman, D.P., Hare, R.A., 2002. Avenues for increasing salt tolerance of crops, and the role of physiologically based selection traits. Plant Soil 247, 93–105.

[19] Noble, C.L. and Rogers, M.E. 1992. Arguments for the use of physiological criteria for improving the salt tolerance in crops. Plant Soil 146: 99–107

[20] Romero, L., Belakbir, A., Ragala, L., Ruiz, J.M., 1997. Response of plant yield and leaf pigments to saline conditions: effectiveness of different rootstocks in melon plants (*Cucumis melo* L.). Soil Sci. Plant Nutr. 43, 855–862.

[21] Rubio, J.S., Garcia-Sanchez, F., Rubio.F. and Martınez, V. 2009. Yield, blossom-end rot incidence, and fruit quality in pepper plants under moderate salinity are affected by K+ and Ca2+ fertilization. Scientia Horticulture. 119:79–87.

[22] Ruiz, J.M., Sanchez, E., Garcıa, P.C., Lopez-Lefebre, L.R., Rivero, R.M., Romero, L., 2002. Proline metabolism and NAD kinase activity in green bean plants subjected to cold-shock. Phytochemistry 59, 473–478.

[23] Sairam, R.K., Rao, K.V., Srivastava, G.C., 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.

[24] Sykes, S. R. 1965. A glasshouse screening procedure for identifying citrus hybrids which restrict chloride accumulation in shoot tissues. Aust. J. Agric. Res. 36:779-789.

[25] Tal, M. and Shannon, M.C.1983. Salt tolerance in the wild relatives of the cultivated tomato: Responses of *Lycopersicon esculentum*, *L.cheesmanii*, *L. peruvianum, Solanum uennellii* and F1 hybrids to high salinity. Aust. J. Plant Physiol. 10: 109–117

[26] Weimberg, R, and Shannon, M.C. 1988. Vigor and salt tolerance in 3 lines of tall wheatgrass. Physiol. Plant. 73:232-237.

[27] Wolf, B.1982. A comprehensive system of leaf analysis and its use for diagnosing crop nutrients status. Commun. Soil Sci. Plant Anal. 13, 1035–1059.

[28] Xing, X., Zheng, G, Deng, Z, Xu, Z.2002. Comparative study of drought and salt resistance of different Tricacae genotypes. *Acta Bot. Boreali-Occidentalia Sin.* 22: 1122-1135.

[29] Yamaguchi, T., Blumwald, E. 2005. Developing salt-tolerant crop plants: Challenges and opportunities. Plant Sci., 10(12): 615-620.

[30] Yamaguchi, T. and Blumwald, E. 2005. Developing salt-tolerant crop plants: challenges and opportunities. Trends in Plant Science 10:615–620.