

EVALUATION FOR SALT STRESS TOLERANCE IN TWO STRAWBERRY CULTIVARS

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ABSTRACT

Salt stress conditions have been found to destroy the vital physiological process in plant where slower cell division and cell enlargement or both and limit mineral nutrient uptake with clearly nutritional imbalance. A greenhouse pot experiment was carried out at Agricultural Research Station, Mu'tah University, Jordan to evaluate growth responses and mineral composition of two strawberry cultivars to salt stress by different NaCl levels. Six NaCl levels (0, 25, 50, 75, 100 and 150 mM) and two strawberry cultivars, Camarosa and Albino, were used. Nutrient elements were added at the 0.5-strength Hoagland nutrient concentration. Distilled water supplemented with half strength Hoagland solution was used as control. Number of leaves and runners of both strawberry cultivars were significantly reduced by increasing NaCl level. Growth parameters (shoot, root and total dry weights and root: Shoot ratios) were significantly reduced with each increase in salinity level. Camarosa had higher value for all these parameters compared with Albino. Leaf chlorophyll content of both strawberry cultivars was significantly decreased when 25 mM NaCl or higher was applied. Regardless of NaCl level, Camarosa cultivar had significantly higher chlorophyll content compared with Albino. Elevated salinity level significantly increased leaf proline content of both cultivars. Albino leaves accumulated higher proline compared with Camarosa at salinized and non-salinized treatments. Both strawberry cultivars had significantly higher leaf and root Na and Cl contents under salinized conditions compared with non-salinized conditions. Each increase in NaCl level resulted in an increase in leaf and root Na and Cl contents of both cultivars. On contrast, leaf K content was decreased with salinity, root content of this mineral was significantly increased with salinity. It could be recommended to avoid growing 'Camarosa' and 'Albino' strawberry using irrigation water of 25 mM NaCl or more.

Keywords: Strawberry, Salinity, Growth, Chlorophyll, Proline, Mineral Composition

1. INTRODUCTION

Strawberry (*Fragaria X Ananassa* Duch) belongs to Rosaceae family (Zebrowska and Hortynski, 2002). According to FAO (2004), world strawberry production reached about 3.1 million tons and the total planted area was 214,200 ha. The highest production (840,000 tons) was recorded in USA. In Jordan, strawberries are mainly cultivated for fresh consumption for local and export markets in the winter growing season that extends from December to March. It has been produced at a significant scale in Jordan for 20 years (Guillaud,

2004). The area cultivated by strawberry in Jordan was about 300 dunum's in the Jordan Valley and 150 dunum's in the highlands. The total annual production was about 1500 to 2000 tons.

Secondary salinization from irrigation water is a growing worldwide problem as more than 6% of agricultural land has become saline (Ghassemi *et al.*, 1995). Salinity is an environmental stress that limits growth, development and productivity of many plants (Khan *et al.*, 1994). Salinity is prevalent in both irrigated and dry areas. In irrigated areas, salinity levels increased due to the use of poor quality water for

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irrigation (Al-Karaki, 2000a) and application of large amounts of fertilizers. However, in dry areas, salinity levels increased when precipitation is not enough to remove excess soluble salt from the soil (Al-Karaki, 2000b). The use of saline water and wastewater in agriculture is considered as one of the alternative sources of irrigation water in countries which suffer from shortage of fresh water, such as Jordan and other Mediterranean countries. However, irrigation with such water is often associated with build up of salts in soil. In Jordan, the average amount of salts deposited in the soil profile by irrigation water was found to range from 3500 to 6000 kg for each hectare per year (Al-Abed, 1999). The response of plants to excess NaCl is complex and involves changes in their morphology, physiology and metabolism (Hilal *et al.*, 1998).

In general, crops differ in their ability to grow successfully under saline conditions and accumulate high concentration of salt in their tissues (Mohammad *et al.*, 1998). Genetic variation in salt tolerance among lines vs strains and cultivars has been reported for many plant species (Shannon, 1997 as cited by Shibli *et al.*, 2000). Strawberry was classified as moderately sensitive to high level of salt (Maas and Hoffman, 1977, D'Anna *et al.*, 2003).

Salt stress conditions have been reported to destroy the vital physiological process in plant where slower cell division and cell enlargement or both were observed in the growing region. Limitation in mineral nutrient uptake with clearly nutritional imbalance is also reported (Makhadmeh *et al.*, 2002). Plants grown under saline conditions cope with salinity through several mechanisms which have been proposed to improve salt tolerance in sensitive plants. Mechanisms involve the accumulation of compatible solutes to for osmotic adjustment or osmoprotection of intracellular component (Meloni *et al.*, 2001). These include betain, free amino acids, soluble carbohydrates and mainly proline (Makhadmeh *et al.*, 2002). The objectives of this study are to evaluate growth responses of two strawberry cultivars to salt stress by different NaCl levels and to study the influence of NaCl levels on mineral composition, proline and chlorophyll contents.

Leaf number of strawberry reduced by 64.73% in Chandler cultivar at 34 mM NaCl compared with the control treatment, on the other hand, no reduction in leaf number in Camarosa at 8.5mM NaCl observed (Saied *et al.*, 2005). The number of runners of strawberry as well as the length of the longest runner was significantly influenced by the salinity treatment (Ondrasek *et al.*, 2006). Kaya *et al.* (2002) reported that dry weight of strawberry decreased when high NaCl

(35 mM) was applied alone compared to the control, this effect was slightly greater in Camarosa than Oso Grande. On other study, Kepenek and Koyuncu, (2002) reported that salinity decreased dry weight of strawberry plant at salt levels ranging between 10-16 mol L⁻¹ NaCl. Plant growth of Elsanta strawberry cv was depressed by NaCl salinity (30, 60 mmol L⁻¹) more than Korona, reduction of dry mass was most distinct for leaves, petioles and roots.

Plants grown at high NaCl produced less chlorophyll than those at normal nutrient solution for two strawberry cultivars (Kaya *et al.*, 2003). Free proline content in leaves of mulberry was significantly elevated in the stressed plants over control plants of two mulberry genotypes at all NaCl concentrations (0, 0.5, 1.0 and 1.5% (w/v) NaCl). There was a liner increase in free proline accumulation with increasing severity and duration of stress (Kumar *et al.*, 2003). Lutts *et al.* (1999) reported that proline accumulation is a symptom of salt stress injury in rice and that it's accumulation in salt sensitive plant results from an increase in Ornithine-Aminotrans Ferase (OAT) activity and an increase in the endogenous pool of its precursor glutamate. Also, at 200 molm⁻³ NaCl, proline concentration in the cotton root of Guazuncho cv increased 36% relative to the controls under 50 mol m⁻³ NaCl proline concentration in the leaves of Guazuncho increased by 121% of control (Meloni *et al.*, 2001).

Salinity increased amount of Na concentration in the plant when the salt applied to the aerial part of plant (Turhan and Atilla, 2004). Kaya *et al.* (2002) reported that Na concentration increased in leaves of two strawberry cultivars in the presence of NaCl stress. In the roots of strawberry plants, salt applications increased the amount of Na and Cl contents and decreased the amount of K and Mg (Turhan and Atilla, 2004). Salt applications in the arial part of the strawberry plant had generally increased the amount of chlorine while the amount of K had decreased (Turhan and, 2004). Nucleous and Vasilakakis (2007) reported that chloride ions increased significantly in various parts of the red resberry plant with salinity and as a consequence total chloride and sodium concentrations in the plant tissue increased proportionally to salinity in a linear trend. Leaf concentrations of Calcium (Ca) and Potassium (K) were much lower in strawberry plants grown at high NaCl than those in the unstressed treatments (Kaya *et al.*, 2003).

In the roots of strawberry plants, salt applications increased the amount of Na and Cl and decreased the amount of K and Mg. Application of salt in the aerial part of the strawberry plant increased the amount of

magnesium while the amount of potassium had decreased (Turhan and Atilla, 2004). The objective of the current investigation was to study the physiological responses of two strawberry cultivars to osmotic effect of saline irrigation water.

2. MATERIALS AND METHODS

2.1. Treatments

Uniform two strawberry cultivars (Camarosa and Albino) transplants were used in this experiment. The transplants were planted in plastic pots (20 cm in diameter and 20 cm in height), containing sandy loam soil in a partially controlled greenhouse located at Agricultural Research Station which belonged to College of Agriculture, University of Muthah. One 4 weeks old transplant was planted in each pot. At the bottom of each pot, there were many holes to facilitate drainage water. Transplants were irrigated with distilled water two times weekly; after 15 days of transplantation, six levels of NaCl (0, 25, 50, 75, 100 and 150 mM) were added to the irrigation water. Nutrient elements were added at the 0.5-strength Hoagland nutrient concentration (Hoagland and Arnon, 1950). Distil water supplemented with half strength Hoagland solution was used as control.

2.2. Growth

Number of leaves and runners per plant, shoot and root dry weight were counted at the end of the experiment. Two strawberry plants per treatment were taken and their leaves were counted. Two freshly harvested plants per treatment were separated in two root and shoot and then were dried in an oven at 70°C for 72 h to a constant weight.

2.3. Leaf Chlorophyll Content

Half gram of fully expanded fresh leaves was taken to determine total chlorophyll, two months after application of NaCl, then it was homogenized in 10ml of 80% acetone. After filtration, the extraction was repeated with another 10ml of 80% acetone. The combined filtrates were made up to 25mL with acetone. Total chlorophyll content was determined according to Harborne, (1973).

2.4. Leaf Proline Content

Leaf proline content was calorimetrically estimated in fresh leaf samples from the two cultivars two months after beginning of the investigation according to the method of Bates *et al.* (1973).

2.5. Mineral Composition

For mineral analysis, the leaves and roots were washed in distilled water to remove any dust and then dried at 70°C for 72 h to a constant weight. The dried leaves and roots were ground to powder and stored. The tissues were digested using nitric acid. For chloride (Cl⁻¹) extraction, 0.5 gm of oven-dried samples were added to 25 mL of deionized water and heated for 30 min at 70°C then filtered and washed with a further 25 ml of deionized water (Bradfield and Cooke 1985). Sodium (Na), Potassium (K), Calcium (Ca) and Magnesium (Mg) were determined by Pye Unicam SP9 atomic absorption spectrophotometer. Chloride was determined by AgNO₃ titration method (Tandon, 1995).

2.6. Experimental Design and Statistical Analyses

Experimental treatments were arranged as factorial in completely randomized block design with 3 replications for each treatment. MSTAT-C statistical package was used to analyze the data that obtain from the experiments. Analysis of variance was determined and Least Significant Differences (LSD) was conducted to determine the mean separations of means.

3. RESULTS

3.1. Growth

Increasing salt level significantly decreased leaf number, runner number and shoot dry weight of both strawberry cultivars compared with the control (**Table 1 and 2**). The significant reduction in the leaf number was observed at all salinity levels of 25 mM NaCl or higher. Regardless of salinity level, strawberry cultivars showed a pronounced variation in leaves number per plant. Camarosa cv significantly gave higher leaves and runners per plant and had higher shoot dry weight compared with Albino cv at salinized and non-salinized treatments. However, both cultivars showed similar trend in response to salinity level with respect to leaves per plant. In this study NaCl toxicity symptoms appeared as chlorosis at concentration higher than 50 mM.

A significant variation in shoot dry weight was observed between two strawberry cultivars at salinized treatments (**Table 3**); Camarosa had higher shoot dry weight (3.57 gm) compared with Albino (1.87 gm). Generally dry weight of strawberry shoot of both cultivars had significantly decreased with increasing salinity level.

Table 1. Number of leaves of strawberry cultivars as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Number of leaves	
	Camarosa	Albino
Control	18.3 a*	12.3 d
25	17.3 b	10.3 f
50	15.3 c	9.0 g
75	13.0 d	8.0 h
100	11.3 e	7.0 i
150	9.0 g	6.0 j

* Means followed by the same letter (s) are not significantly different at $p \leq 0.05$

Table 2. Number of runners of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Number of runners	
	Camarosa	Albino
Control	3.3 a*	1.0 c
25	3.3 a	1.0 c
50	2.0 b	1.7 b
75	1.0 c	0.001 d
100	1.0 c	0.67 c
150	1.0 c	0.001 d

*Means followed by the same letter (s) are not significantly different at $p \leq 0.05$

Table 3. Shoot dry weight of strawberry cultivars as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Shoot dry weight (gm)	
	Camarosa	Albino
Control	5.93 a*	2.23 f
25	4.20 b	2.36 f
50	3.97 c	3.33 d
75	2.93 e	1.73 h
100	2.30 f	0.89 i
150	2.07 g	0.47 j

*Means followed by the same letter (s) are not significantly different at $p \leq 0.05$ according to LSD

A significant reduction in shoot dry weight was shown upon increasing NaCl concentration more than 25 mM for Albino; however the reduction was more pronounced in Albino than in Camarosa. The lowest dry weight (0.74 g) was produced by Albino at 150 mM NaCl whereas the highest dry weight (5.93 gm) was produced by 'Camarosa' at 0 mM NaCl.

Table 4 shows a significant variation in root dry weight between both tested strawberry cultivars in the control and all salt treated plants. It appears that growth rate of Camarosa was more than Albino. However, both cultivars had the same trend in their response to salinity treatment.

A significant decrease in the root: Shoot ratio was observed at salinity level of 25 mM NaCl or higher (**Table 5**). In general, root: Shoot ratio decreased with increased salinity level. Camarosa strawberry cultivar had a significantly higher root: Shoot ratio compared with Albino cultivar. Regardless of strawberry cultivars, application salinity significantly decreased root: Shoot ratio. These results are in consistency with the results obtained by Al-Harbi (1995) who found that root: Shoot ratio for tomato and cucumber decreased with increasing salinity (2, 4, 8 ms cm^{-1}). The reduction in root: Shoot ratio was significantly for both studied crops (tomato and cucumber) only at 8 ms cm^{-1} salinity levels as compared to the control.

3.2. Chlorophyll Content

Chlorophyll content of strawberry leaves were decreased when 25 mM NaCl or higher were applied compared to the control (**Table 6**). Both strawberry cultivars exhibited genotypic difference in leaf chlorophyll content at salinized and non-salinized treatments. Camarosa cultivar had significantly higher chlorophyll content (23.5) compared with Albino (17.7). However, both cultivars had similar trend in their response to salinity treatments.

3.3. Proline Content

Both strawberry cultivars showed genotypic difference in leaf proline content at salinized and non-salinized treatments (**Table 7**). Albino cultivar had significantly higher accumulation of proline content compared with Camarosa at salinized and non-salinized treatments. However, both cultivars had similar trend in their response to salinity treatments. For Camarosa, proline content of strawberry leaves were increased significantly when 50 mM NaCl or higher were applied compared to the control, while for Albino. Each increase in salinity level resulted in a significant increase in leaf proline content.

3.4. Mineral Composition

Increasing salt level increased Na content in leaves and roots (**Table 8**), the significant increase in leaves and root Na content was observed at salinity level of 25 mM NaCl or higher. Camarosa strawberry cultivar had a significantly higher leaf Na content compared with Albino cultivar. However, root Na contents of Albino at all NaCl concentrations were higher than those of Camarosa. Both cultivars have similar trend in their response to salinity treatments.

Table 4. Root dry weight of strawberry cultivars as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Root dry weight (gm)	
	Camarosa	Albino
Control	4.53 a*	1.23 e
25	2.80 b	0.69 g
50	2.30 d	1.33 e
75	1.97 d	0.54 gh
100	1.27 e	0.40 hi
150	0.97 f	0.26 i

*Means followed by the same letter (s) are not significantly different at $P \leq 0.05$ according to LSD

Table 5. Root/shoot dry weight of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Root/shoot dry weight	
	Camarosa	Albino
Control	0.77 a*	0.55 c
25	0.67 b	0.29 f
50	0.58 c	0.39 e
75	0.67 b	0.31 f
100	0.55 c	0.44 de
150	0.47 d	0.55 c

*Means followed by the same letter (s) are not significantly different at $p \leq 0.05$ according to LSD

Table 6. Leaf chlorophyll content of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Leaf chlorophyll content ($\mu\text{g/gm}$ fresh weight)	
	Camarosa	Albino
Control	28.1 a*	22.7 d
25	25.8 b	20.2 e
50	24.9 c	19.1 f
75	22.8 d	15.8 h
100	20.5 e	14.5 i
150	18.7 g	13.8 j

*Means followed by the same letter (s) are not significantly different at $p \leq 0.05$ according to LSD

Table 7. Proline content of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Proline content (ppm)	
	Camarosa	Albino
Control	1.00 j	5.30 g
25	1.10 j	7.03 f
50	2.03 i	7.70 e
75	4.67 h	17.87 c
100	6.70 f	28.30 b
150	12.60 d	33.17 a

*Means followed by the same letter (s) are not significantly different at $P \leq 0.05$ according to LSD

Table 8. Leaf and root sodium content of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Strawberry cultivar	
	Camarosa	Albino
Leaf Na content (ppm)		
Control	84.7 j	69.7 k
25	136.0 h	114.7 i
50	145.0 g	134.0 h
75	163.7 e	153.0 f
100	211.3 c	182.0 d
150	250.7 a	240.7 b
Root Na content (ppm)		
Control	18.7 l	51.0 j
25	31.7 k	71.7 h
50	60.3 i	125.3 f
75	110.3 g	152.7 d
100	150.3 e	152.7 d
150	181.3 c	250.3 a

*Means followed by the same letter (s) are not significantly different at $p \leq 0.05$ according to LSD

It is clear from **Table 9** that leaf Na contents in Camarosa at 100 and 150 mM NaCl were higher than those of roots. However, in Albino the root Na contents were higher than those of leaves.

A significant variation in potassium content was observed between the two strawberry cultivars at salinized and non-salinized treatments (**Table 9**). Camarosa had higher leaf potassium content (188 ppm) compared to Albino (177 ppm). Generally, potassium content of strawberry leaves of both cultivars had significantly decreased with increasing salinity level in the irrigation water. The lowest leaf potassium content (98.33 ppm) was produced by Albino at 150 mM NaCl whereas the highest leaf potassium content (198.0 ppm) was produced by Camarosa at 0 mM NaCl. On the contrary, root potassium content was significantly increased by increased salinity level of both strawberry cultivars. A significant increase in root potassium content was showed when salinity increased more than 0 mM, however the increase was more pronounced in Camarosa than Albino. Camarosa produced the highest root potassium content (713.3 ppm) at 150 mM NaCl compared with Albino (615.3 ppm) at 150 mM NaCl.

The chloride levels in both leaves and roots were higher for Camarosa than for Albino (**Table 10**). The Cl accumulation in leaves and roots significantly increased with application of saline water. When the saline treatment was applied during vegetative growth, Cl concentrations were significant to those of the control for leaves and roots.

Table 9. Leaf and root potassium content of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Strawberry cultivar	
	Camaraosa	Albino
Leaf Na content (ppm)		
Control	198.0 a*	177.0 c
25	180.0 b	164.0 d
50	157.7 e	156.7 e
75	144.7 f	126.7 g
100	126.3 g	112.7 h
150	104.3 i	98.33 j
Root Na content (ppm)		
Control	445.3 k	455.3 j
25	454.3 j	470.3 i
50	511.3 h	530.0 g
75	586.7 e	569.0 f
100	687.7 b	595.7 d
150	713.3 a	615.3 c

*Means followed by the same letter (s) are not significantly different at $P \leq 0.05$ according to LSD

Table 10. Leaf and root chloride content of strawberry as influenced by different NaCl concentrations

Salinity level (mM NaCl)	Strawberry cultivar	
	Camaraosa	Albino
Control	218.3 i*	181.0 k
25	250.0 g	202.3 j
50	296.7 e	228.0 h
75	364.7 d	255.3 g
100	418.3 b	286.3 f
150	520.7 a	408.3 c
Control		
25	181.0 g	149.3 i
50	202.3 f	165.7 h
75	228.0 e	182.3 g
100	255.3 d	205.3 f
150	286.3 b	234.0 e
150	319.0 a	277.0 c

4. DISCUSSION

The clear reduction in vegetative growth observed in this study could be attributed to the combined effect of osmotic stress as well as sodium and chloride toxicity especially at the higher concentration of NaCl. Shibli *et al.* (2001) reported that effect of salinity on plant was expressed as reduction in shoot dry weight because vegetative growth is the most widely used index in salt tolerance studies. The present results are in harmony with those obtained by Al-Karaki (2000a). The reduction in shoot dry matter could be a result of salinity induced water stress which inhibits photosynthesis and subsequent failure in the translocation of assimilates (Al-Harbi *et al.*, 2002; Keutgen and Pawelzik, 2009).

Concerning root dry weight, the current results agreed the findings of Saied *et al.* (2005) who found that strawberry plant growth was depressed by NaCl salinity in the root medium and it was more pronounced in 'Elsanta more than in 'Korona'. Similar results of chlorophyll content have been observed by Necleous and Vasilakakis (2007) who found that sodium chloride application reduced chlorophyll content and this reduction was statistically significant at concentration ≥ 10 mM NaCl. The decrease in leaf chlorophyll content was attributed to the clear increase in chlorophyllase activity that may be caused the depressive effect of salinity on the absorption of some ions such as Mg and Fe which is involved in the chloroplast formation (Hanafy *et al.*, 2002).

The current results appeared that proline content increased with increasing electrolyte concentration of the irrigation water. Similar to this result, Somal and Yapa (1998) found that leaf proline content increased as a result of drought stress as well as to increasing salt concentration. Accumulation of free proline has been correlated with tissue Na ion concentration for numerous plant species which strongly suggests a possible role in osmoregulation during salt stress (Gunes *et al.*, 1996). A positive correlation was found between leaf proline content and leaf Na content in the current investigation. Accumulation of proline in plant tissues as a response to salt stress has been attributed to enhanced activities of the enzyme involved in proline biosynthesis (Charest *et al.*, 1990) and to inhibition of proline oxidase catabolizing enzyme (Yoshida *et al.*, 1997).

There is a clear variation in the two strawberry cultivars in their response to absorption and accumulation of minerals. In Camaraosa, at high salt concentrations, the accumulation of Na in leaves was more than roots, however, in Albino the root Na contents were higher than those of leaves. The trend may be explained that Albino has the ability to exclude Na from leaves by accumulation of it in its roots. On the contrary this mechanism is not involved clearly in Camaraosa.

Accumulation patterns of Na in this study were partially similar to those reported for red raspberry (Necleous and Vasilakakis, 2007). Accumulation of high levels of Na can displace Ca from membrane to change their integrity and effect membrane selectivity for K uptake (Al-Karaki, 2000b). The efflux of ^{22}Na was generally higher and differed considerably between the plant species, ranging from zero in sugar beet to 14% in bean. The leaf K contents of both strawberry cultivars reduced with increasing salinity, while leaf Cl content increased. Under saline conditions, the K^+ concentration

in many glycophytes is severely reduced (Greenway and Munns, 1980). Epstein *et al.* (1966) and Chartzoulakis and Klapaki (2000) found that the reduction in K content with the increase in salinity could be due to the direct competition between K and Na at sites of uptake at the plasmalemma. Greenway and Munns (1980) reported that the reduction in K concentration can inhibit growth by reduction capacity for osmotic adjustment and turgor maintenance or by adversely affecting metabolic functions. The Cl accumulation and a possible osmotic effect, could be responsible for the differences between the two cultivars in their response to salinity application. The Cl concentration was lower in roots than in leaves in both strawberry cultivars. The reduction in K concentration can inhibit growth by reduction capacity for osmotic adjustment and turgor maintenance or by adversely affecting metabolic functions (Greenway and Munns, 1980).

5. CONCLUSION

The results of the current study indicate that strawberry is classified as salt sensitive species with significant variation between genotypes. It could be concluded that the salinity threshold for both used cultivars, at which a considerable decrease in relative yield per unit of salt, is more than 25 mM. It could be recommended to avoid growing 'Camarosa' and 'Albino' strawberry using irrigation water of 25 mM NaCl (1460.8 ppm = 2.28 dS/m) or more. Thus, identifying the physiological mechanisms and adjustments in strawberry under salinity as well as the threshold water potential at which physiological dysfunction begins to occur, would provide an understanding and help in developing adaptation strategies to protect this crop in the event of unexpected salinity. Screening genotypes for salt tolerance may be a rapid method of identifying which are most likely to survive when planted at salinized areas.

6. REFERENCES

- Al-Abed, N., 1999. Using Geographical Information Systems (GIS) to identify and manage agricultural information areas having salinity problems. Proceedings of the Irrigation Management and Saline Conditions, (MSC' 99), Jordan, pp: 387-404.
- Al-Harbi, A.R., H.H. Hegazi, A.A. Alsadon and F. El-Adgham, 2002. Growth and yield of onion (*Allium cepa* L.) cultivars under different levels of irrigation water salinity. J. Kingdom Saudia Univ., 14: 33-41.
- Al-Karaki, N.G., 2000a. Growth, sodium and potassium uptake and translocation in salt stressed tomato. J. Plant Nutrit., 23: 369-379. DOI: 10.1080/01904160009382023
- Al-Karaki, N.G., 2000b. Growth, water use efficiency and sodium and potassium acquisition by tomato cultivars grown under salt stress. J. Plant Nutrit., 23: 1-8. DOI: 10.1080/01904160009381992
- Bates, L.S., R.P. Waldren and I.D. Teare, 1973. Rapid determination of free proline for water-stress studies. Plant Soil, 39: 205-207. DOI: 10.1007/BF00018060
- Bradfield, E.G. and D.T. Cooke, 1985. Determination of inorganic anions in water extracts of plants and soils by ion chromatography. Analyst, 110: 1409-1410. DOI: 10.1039/AN9851001409
- Charest, C. and T. Pan, 1990. Cold acclimation of wheat (*Triticum aestivum*): Properties of enzymes involved in proline metabolism. Physiol. Plant., 80: 159-168. DOI: 10.1111/j.1399-3054.1990.tb04391.x
- Chartzoulakis, K. and G. Klapaki, 2000. Response of two greenhouse pepper hybrids to NaCl salinity during different growth stages. Sci. Horticulturae, 86: 247-260. DOI: 10.1016/S0304-4238(00)00151-5
- D'Anna, F.D., G. Incalcaterra, A. Moncada and A. Miceli, 2003. Effects of different electrical conductivity levels on strawberry grown in soilless culture. Acta Horticulturae, 609: 355-360.
- Epstein, E., J.D. Norlyn, R.W. Rush, R.W. Kingsbury and D.B. Kelly *et al.*, 1980. Saline culture of crops: A genetic approach. Science, 210: 399-404. DOI: 10.1126/science.210.4468.399
- FAO, 2004. The State of World Fisheries and Aquaculture 2004. 1st Edn., Food and Agriculture Org., ISBN-10: 9251051771, pp: 168.
- Ghassemi, F., A.J. Jakerman and H.A. Nix, 1995. Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies. 1st Edn., CAB International, Sydney, ISBN-10: 0851989063, pp: 526.
- Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant Physiol., 31: 149-190. DOI: 10.1146/annurev.pp.31.060180.001053
- Guillaud, J., 2004. MREA-Ministry of Agriculture/NCARTT-JEPAFV support to fruits and vegetables export program strawberry action and experiments assessment. Ambassade De France MREA.

- Gunes, A., A. Inal and M. Alpaslan, 1996. Effect of salinity on stomatal resistance, proline and mineral composition of pepper. *J. Plant Nutr.*, 19: 389-396. DOI: 10.1080/01904169609365129
- Hanafy, A.H., M.A. Gad-Mervat and A.A. Amin-Mona, 2002. Improving growth and chemical composition of *myrtus communis* grown under soil salinity conditions by polyamine foliar application. *Proc. Minia-Egypt J. Agric. Res. Dev.*, 22: 1697-1720.
- Harborne, J.B. 1973. Chlorophylls. In: *Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis*, Harborne, J.B. (Ed.), pp: 215-222.
- Hilal, M., M. Zenff, G. Ponessa, H. Moreno and M. E. Massa, 1998. Saline stress alters the temporal patterns of xylem differentiation and alternative oxidase expression in developing soybean roots. *J. Plant Physiol.*, 117: 695-701. DOI: 10.1104/pp.117.2.695
- Hoagland, D. R. and D. I. Arnon, 1950. The water-culture method for growing plants without soil. *Univ. California Agric. Exp. Stn.*, 347: 32-32.
- Kaya, C., B. Erol and D. Higgs, 2002. Response of salt-stressed strawberry plants to supplementary calcium nitrate and/or potassium nitrate. *J. Plant Nutr.*, 26: 543-560. DOI: 10.1081/PLN-120017664
- Kepenek, K. and F. Koyuncu, 2002. Studies on the salt tolerance of some strawberry cultivars under glasshouse. *Acta Horticulturae*, 573: 625-629.
- Keutgen, A.J. and E. Pawelzik, 2009. Impacts of NaCl stress on plant growth and mineral nutrient assimilation in two cultivars of strawberry. *Environ. Exp. Botany*, 65: 170-176. DOI: 10.1016/j.envexpbot.2008.08.002
- Khan, G.M., M. Silberbush and H.S. Lips, 1994. Physiological studies on salinity and nitrogen interaction in alfalfa. I. Biomass production and root development. *J. Plant Nutr.*, 17: 657-668. DOI: 10.1080/01904169409364756
- Kumar, A., J.B. Cameron and P.C. Flynn, 2003. Biomass power cost and optimum plant size in western Canada. *Biomass Bioenergy*, 24: 445-464.
- Lutts, S., V. Majerus and J.M. Kinet, 1999. NaCl effects on proline metabolism in rice (*Oryza sativa*) seedlings. *Physiol. Plantarum*, 105: 450-458. DOI: 10.1034/j.1399-3054.1999.105309.x
- Maas, E.V. and G.J. Hoffman, 1977. Crop salt tolerance-current assessment. *J. Irrigat. Drainage, Divis. ASCE*, 103: 115-134.
- Makhadmeh, I., A. Abu-Khadejeh, R. Shibli and M.J. Mohammad, 2002. Physiological responses of tomato (*Lycopersicon esculentum* Mill.) microshoots to salinity. *J. Plant Nutr.*, 25: 124-132.
- Meloni, A.D., A.M. Oliva, A.H. Ruiz and A.C. Martinez, 2001. Contribution of praline and inorganic solutes to osmotic adjustment in cotton under salt stress. *J. Plant Nutr.*, 24: 599-612.
- Mohammad, M., R. Shibli, M. Ajlouni and L. Nimri, 1998. Tomato root and shoot responses to salt stress under different levels of phosphorus nutrition. *J. Plant Nutr.*, 21: 1667-1680. DOI: 10.1080/01904169809365512
- Necleous, D. and M. Vasilakakis, 2007. Effects of NaCl stress on red raspberry (*Rubus idaeus* L. 'Autumn Bliss'). *Sci. Horticulturae*, 112: 282-289. DOI: 10.1016/j.scienta.2006.12.025
- Ondrasek, G., D. Romcic, M. Romcic, B. Duralija and I. Mustak, 2006. Strawberry growth and fruit yield in a saline environment. *Agric. Conspectus Sci.*, 71: 155-158.
- Saied, S.A., J.A. Keutgen and G. Noga, 2005. The influence of NaCl salinity on growth, yield and fruit quality of strawberry cvs. 'Elsanta' and 'Korona'. *Sci. Horticulturae*, 103: 289-303.
- Shannon, M.C., 1997. Adaptation of plants to salinity. *Adv. Agron.*, 60: 76-120.
- Shibli, R., M. Mohammad, A. Abu-Ein and M. Shatnawi, 2000. Growth and micronutrient acquisition of some apple varieties in response to gradual *in vitro* induced salinity. *J. Plant Nutr.*, 23: 1209-1215. DOI: 10.1080/01904160009382094
- Shibli, A.R., J. Sawwan, I. Swaidat and M. Tahat, 2001. Increased phosphorus mitigates the adverse effects of salinity in tissue culture. *Commun. Soil Sci. Plant Anal.*, 32: 429-440. DOI: 10.1081/CSS-100103019
- Somal, C.L.T. and J.A.P. Yapa, 1998. Accumulation of proline in cowpea under nutrient, drought and saline stresses. *J. Plant Nutr.*, 21: 2465-2473. DOI: 10.1080/01904169809365578
- Tandon, H.L.S., 1995. *Methods of Analysis of Soils, Plants, Waters and Fertilizers*. 1st Edn., Fertilizer Development and Consultation Organization, New Delhi, pp: 82.
- Turhan, E. and E. Atilla, 2004. Effects of sodium chloride applications and different growth media on ionic composition in strawberry plant. *J. Plant Nutr.*, 27: 1653-1665. DOI: 10.1081/PLN-200026009
- Yoshiba, Y., T. Kiyosue, K. Nakashima, S. K. Yamaguchi and K. Shinozaki, 1997. Regulation of levels of proline as an osmolyte in plants under water stress. *Plant Cell Physiol.*, 83: 1095-1102.
- Zebrowska, J.I. and J. Hortynski, 2002. Plant regeneration from leaf explants in strawberry (*Fragaria x Ananassa* Duch.). *Acta Horticulture*, 567: 313-320.