Vitis **53** (4), 181–188 (2014)

Ameliorative effects of salicylic acid on mineral concentrations in roots and leaves of two grapevine (*Vitis vinifera* L.) cultivars under salt stress

J. Amiri[1), 2)], S. Eshghi[1)], E. Tafazoli[1)], B. Kholdebarin[3)] and N. Abbaspour[4)]

[1)] Department of Horticultural Science, Faculty of Agriculture, Shiraz University, Shiraz, Iran
[2)] Department of Horticultural Sciences, Faculty of Agriculture, University of Urmia, Urmia, Iran
[2)] Department of Biology, Faculty of Science, Shiraz University, Shiraz, Iran
[3)] Department of Biology, Faculty of Science, Urmia University, Urmia, Iran

Summary

Salicylic acid (SA) acts as an endogenous signal molecule, synchronizing plant responses under abiotic stress and a component of tolerance in plants. The current study investigates the effects of SA on mineral nutrient concentrations in two grapevine (*Vitis vinifera* L.) cultivars, 'Qarah Shani' and 'Thompson Seedless' under NaCl stress. Grapevine rooted cuttings were planted in pots, containing a mixture of perlite and cocopeat (1:1 v/v) and placed in an open hydroponic system. Plants were exposed to five levels of salinity 0, 25, 50, 75 and 100 mM NaCl and four levels of SA 0, 100, 200 and 300 mg·L^{-1}. Results indicated that foliar spray with SA improved nutrient uptake by grape roots. Plant's leaves and roots Na^+ and Cl^- contents increased significantly, and NO_3^--N, K^+, Na^+, Ca^{2+}, Mg^{2+}, Zn^{2+}, Fe^{2+} and also K^+/Na^+ selectivity ratios decreased in both cultivars in response to salt treatments. Application of SA significantly reduced Na^+ and Cl^- accumulation in leaves and roots in both cultivars and it increased NO_3-N, K^+, Ca^{2+}, Mg^{2+}, Zn^{2+} and Fe^{2+} contents under NaCl stress. Therefore, SA could mitigate the detrimental effects of salinity on accumulation of harmful ions and improve the absorption of essential and beneficial elements in grapevine under salinity.

Key words: grapevine, salicylic acid, salinity, nutrient concentration, growth parameters.

Introduction

During their life cycles, plants often experience abiotic stresses such as salinity, drought, high and low intensity of heat, flooding, metal and ozone toxicity, UV-radiations, herbicides and other chemical pollutants posing serious threats in crop production (Parvaiz *et al.* 2013). Salinity is one of the most serious environmental factors, limiting the productivity of agricultural crops due to its both osmotic and toxic effects (Munns and Tester 2008). The deleterious effects of salinity on plant growth are associated with low osmotic potential of soil solution (water stress), nutritional imbalance and specific ion effect (Parvaiz and Satyawati 2008).

Grapevine (*Vitis vinifera* L.) is usually grown in semi-arid areas where drought and salinity are the most common problems (Cramer *et al.* 2007). Field studies suggest that grapevines should be classified as moderately sensitive to salinity (Prior *et al.* 1992, Stevens *et al.* 1999). The adverse effects of salt stress on grapevines have been well documented. Salinity can reduce photosynthesis through a decline in leaf expansion rates, decrease root and shoot vigor, cause leaf burn or leaf death, particularly in old leaves, decrease yields and ultimately lead to plant death (Fisarakis *et al*. 2001, Munns 2002, Walker *et al.* 2002).

Compounds, reducing damaging effects of stresses are of great interest from application point of view. In the current study, we focused on the salt-tolerance-inducing role of salicylic acid in 'Thompson Seedless' and 'Qarah Shani' grapevine cultivars. Salicylic acid is a phytohormone with ubiquitous distribution among plants (Raskin 1992, Wang and Li 2006). Salicylic acid is also known as an important signal molecule for modulating plant responses to environmental stresses (El-Tayeb 2005).

By improving the rates of mineral nutrient uptake and reducing Na^+ and Cl^- uptake, Salicylic acid has been reported to manage the deleterious salt effects on maize plants (Gunes *et al.* 2007). Gunes *et al.* (2005) found that in salt stress conditions, SA treatments stimulated N, P, K^+, Mg^{2+} and Mn^{2+} accumulation in maize plants. Gharsa *et al.* (2008) concluded that the plants improved tolerance to salt stress was primarily because of higher K^+ absorption resulting in higher K^+/Na^+ ratios. Also, Al-Hakimi and Hamada (2001) observed similar effects of salicylic acid on K^+, Ca^{2+} and Mg^{2+} contents of wheat plants grown under salinity. Aly and Soliman (1998) studied the effects of SA on iron uptake in soybean genotypes and reported that SA was effective in correcting iron chlorosis in the plants grown in calcareous soils. It has also been shown that the damaging effects of salinity were alleviated by exogenous application of SA in *Arabidopsis* (Borsani *et al.* 2001).

There are limited studies have been conducted by different researchers like Kok (2012) on the effects of SA on woody plants responses to salinity stress. Thus the current study indicates the effects of salicylic acid (SA) on mineral nutrient contents in two grapevine (*Vitis vinifera* L.) cultivars, differing in regard to their tolerance under salt stress.

Material and Methods

Plant material and growth conditions: Hardwood cuttings of *Vitis vinifera* L. 'Qarah Shani' and 'Thompson Seedless' with two nodes were

Correspondence to: Dr. S. Eshghi, Department of Horticultural Science, Faculty of Agriculture, Shiraz University, Shiraz, Iran.Fax: +98-711-228-6133. E-mail: eshghi@shirazu.ac.ir

collected in winter 2011 and planted in perlite media for 3.5 months to root. Cuttings with well-developed root systems were transplanted to pots containing a mixture of perlite and cocopeat (1:1 v/v) in an open hydroponic system. The pots were kept in the greenhouse with light/dark period of 16 h/8 h at the average of minimum and maximum temperature of 14.6 ± 2 and 29.5 ± 2 °C respectively and the relative humidity from 40 % to 65 %. The plants were fertigated with the modified ½ strength Hoagland nutrient solution (HOAGLAND and ARNON 1950). The pH of the nutrient solution was adjusted at 6.3.

At the beginning of the experiment, the plants were supplied by 200 mL nutrient solution three times a week. Each time, about 20 % of the nutrient solution was drained from the bottom of the pots. The nutrient solution was replaced, weekly. All vines were trimmed to a single shoot and axillary buds were removed as they appeared.

Application of salt stress: Salt stress was applied to the 100-day-old grapevine plants fertigated by ½ strength Hoagland nutrient solutions. Final concentrations were 25, 50, 75 and 100 mM of NaCl salinity. The control plants only received nutrient solution. The electrical conductivity (EC) of the salt treated solutions at 25 °C was 1.4, 3.6, 7.5 and 11.8 ds/m, respectively. To avoid salinity shock, NaCl was gradually added to the nutrient solutions at the rate of 25 mM a day to reach final salinity level. The experiment lasted for seven weeks.

SA treatments: Concurrent with salinity application, the foliage of grapevines was sprayed with SA at various concentrations (0, 100, 200 and 300 $mg \cdot L^{-1}$). Before spraying, the pH of the solutions was adjusted at 6.5 by 0.1 N NaOH. The control plants were sprayed with deionized water. Tween-20 (0.1 %) was added to all solutions as surfactant. The plants were sprayed with SA solutions at two-week intervals until the end of the experiment.

Tissues mineral nutrient analysis: At the end of the experiment, mature leaves on mid stem and fibrous roots were sampled and rinsed with deionized water and oven-dried at 70 ºC for 48 h. The dried tissues were analyzed for their Na^+, Cl^-, NO_3-N, K^+, Ca^{2+}, Mg^{2+}, Zn^{2+} and Fe^{2+} contents.

The Na^+ and K^+ contents of tissues were analyzed by flame photometry (Fater 405 model, Iran), Cl^- content was analyzed by chloride analyzer (Model 926, Sherwood scientific), and nitrogen as nitrate (NO_3-N) was colorimetrically analyzed by nitration of salicylic acid (CATALDO *et al.* 1975). Another group of samples (leaves and roots) was used to determine Ca^{2+}, Mg^{2+}, Fe^{2+} and Zn^{2+} concentrations. Dried samples (0.4 g) were ground and ashed at 550 °C in a porcelain crucible for 5 h, separately. The white ash was digested in 10 mL HCl (2M), filtered into a 50 mL volumetric flask, and finally, made up to 50 mL with distilled water. Ca^{2+}, Mg^{2+}, Fe^{2+} and Zn^{2+} were analyzed by atomic absorption spectrophotometer (Shimadzu AA-6300).

Statistical analysis: The experiments were performed in a completely factorial randomized design with four replications. Analysis of variance (ANOVA) was performed by means of SAS 9.1 Statistical Software. Treatment means were compared by using Duncan's Multiple Range Test at 1 % level.

Results

Na^+ and Cl^- concentration: The salt treatments significantly increased the sodium contents in both roots and shoots of the two cultivars. Root Na^+ content of both cultivars increased up to the external 50 mM NaCl and then it slowed down with a further increase in the external salinity levels. In the presence of 75 and 100 mM NaCl in external media, the application of 300 $mg \cdot L^{-1}$ SA mitigated Na^+ concentration in the leaves of 'Qarah Shani' to 59.15 % and 11.78 %, respectively, and in the leaves of 'Thompson Seedless' to 37.6 % and 26.20 %, respectively, in comparison with the control plants. (Fig. 1).

In both cultivars, Cl^- content increased in leaves and roots along with augmentation of salt concentration in nutrient solution. Cl^- concentrated more in the leaves than in the roots. The SA treatments reduced Cl^- concentration in leaves and roots of both cultivars significantly under salinity. In the 100 mM NaCl treatment, the application of 300 $mg \cdot L^{-1}$ SA significantly reduced Cl^- concentration in roots of 'Qarah Shani' and 'Thompson Seedless' to 16 % and 8.5 % respectively (Fig. 2).

K^+ and NO_3-N concentration: The presence of NaCl in roots media caused a decrease in K^+ content in leaves and roots of both cultivars, while the application of SA increased K^+ concentration in leaves and roots of the two cultivars. In the 100 mM NaCl treatment, the application of 300 $mg \cdot L^{-1}$ SA significantly increased the K^+ content in roots of 'Qarah Shani' and 'Thompson Seedless' to 76.83 % and 66.81 %, respectively. (Fig. 3).

Salt stress decreased NO_3-N content in the leaves and roots markedly. In the 100 mM NaCl treatments, NO_3-N content in the leaves of 'Thompson Seedless' and 'Qarah Shani' were almost 3.53 and 3.28-folds lower than in the control, respectively but in the roots, it decreased almost 3.5 and 2.04-fold lower than in the control plants. The application of SA significantly increased NO_3-N content in the roots and leaves of both cultivars (Fig. 4).

Ca^{2+} and Mg^{2+} concentration: Ca^{2+} content significantly decreased in leaves and roots when salt concentration in nutrient solution increased. In the 100 mM NaCl treatments, Ca^{2+} content in the leaves of 'Thompson Seedless' and 'Qarah Shani' was almost 2 and 1.49-fold lower respectively as compared with the control. The application of SA significantly increased Ca^{2+} content in both leaves and roots as compared with corresponding salinity levels (Table). Mg^{2+} contents in roots and leaves of both cultivars decreased with an increase in salinity. The application of SA significantly increased Mg^{2+}content in leaves of both cultivars. (Table).

Fe^{2+} and Zn^{2+} concentration: Fe^{2+} content in leaves and roots of both cultivars decreased with an increase in salinity levels. In the 100 mM NaCl treatment, the application of 300 $mg \cdot L^{-1}$ SA did not significantly influence on Fe^{2+} content in leaves of both cultivars. (Table).

The salinity treatments significantly decreased Zn^{2+} content in the leaves and roots. The application of 300 $mg \cdot L^{-1}$ SA did not influence the Zn^{2+} content in the leaves and roots of both cultivars significantly as compared with the control plants (Table).

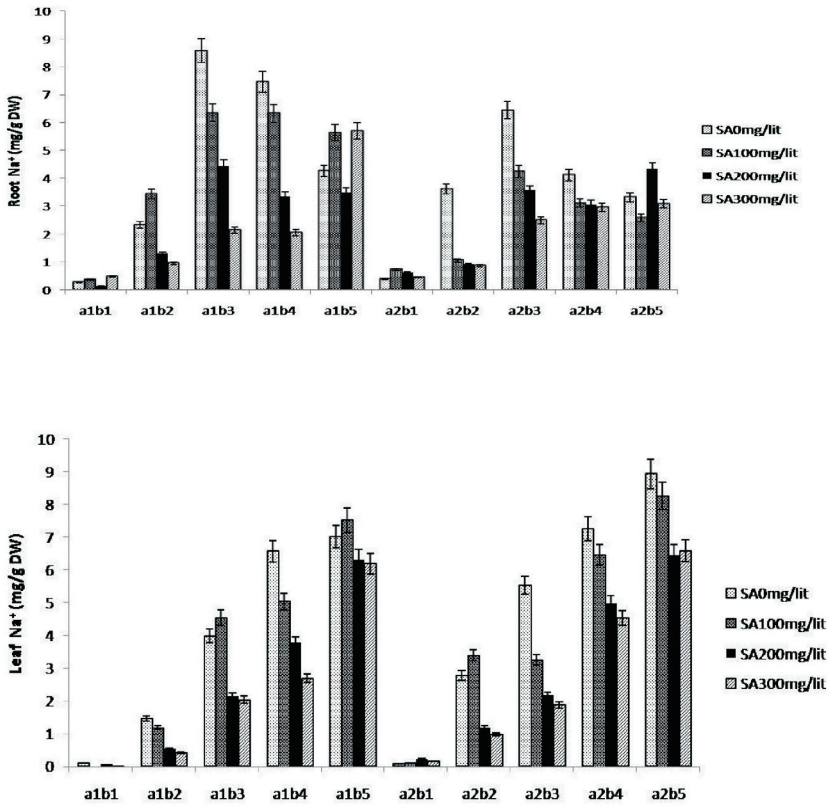

Fig. 1: Interaction of cultivar, salinity and SA on Na^+ contents in roots and leaves of two grapevine cultivars. **a**: cultivar (a1: 'Qarah Shani', a2: 'Thompson Seedless'), **b**: salinity (b1: 0 (control), b2: 25, b3: 50, b4: 75 and b5: 100 mM).

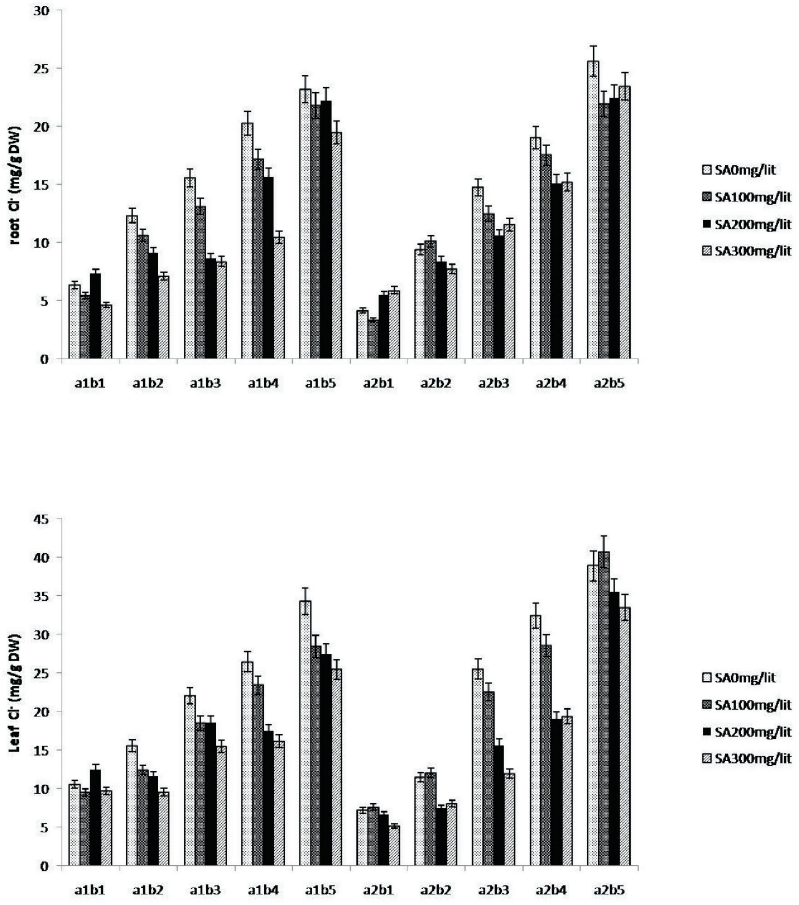

Fig. 2: Interaction of cultivar, salinity and SA on Cl^- contents in roots and leaves of two grapevine cultivars. **a**: cultivar (a1: 'Qarah Shani', a2: 'Thompson Seedless'), **b**: salinity (b1: 0 (control), b2: 25, b3: 50, b4: 75 and b5: 100 mM).

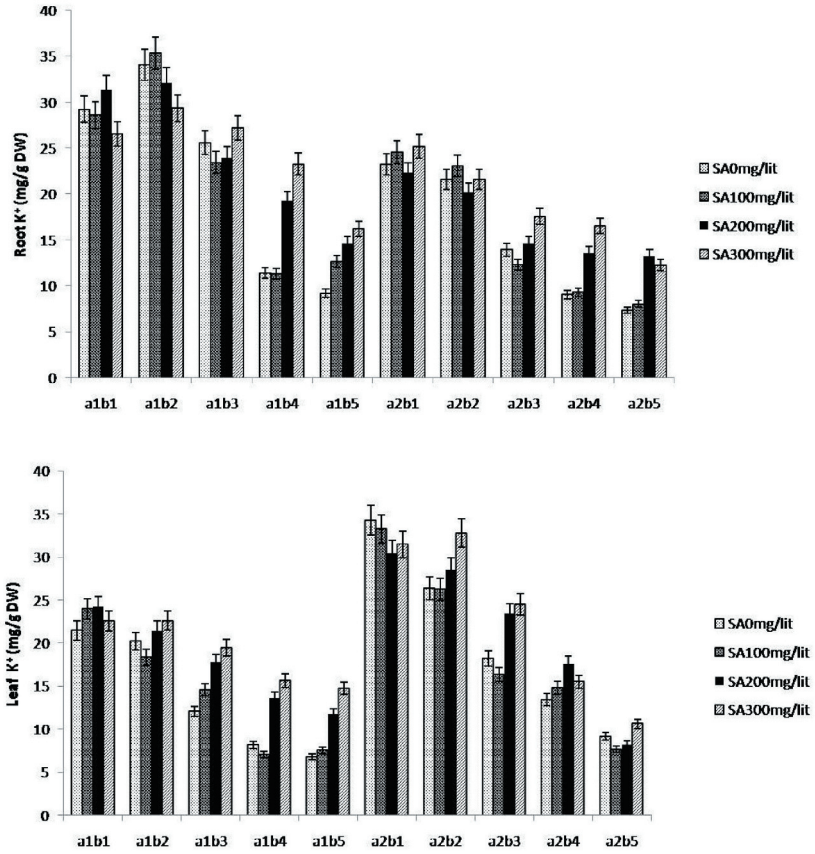

Fig. 3: Interaction of cultivar, salinity and SA on K^+ contents in roots and leaves of two grapevine cultivars. **a**: cultivar (a1: 'Qarah Shani', a2: 'Thompson Seedless'), **b**: salinity (b1: 0 (control), b2: 25, b3: 50, b4: 75 and b5: 100 mM).

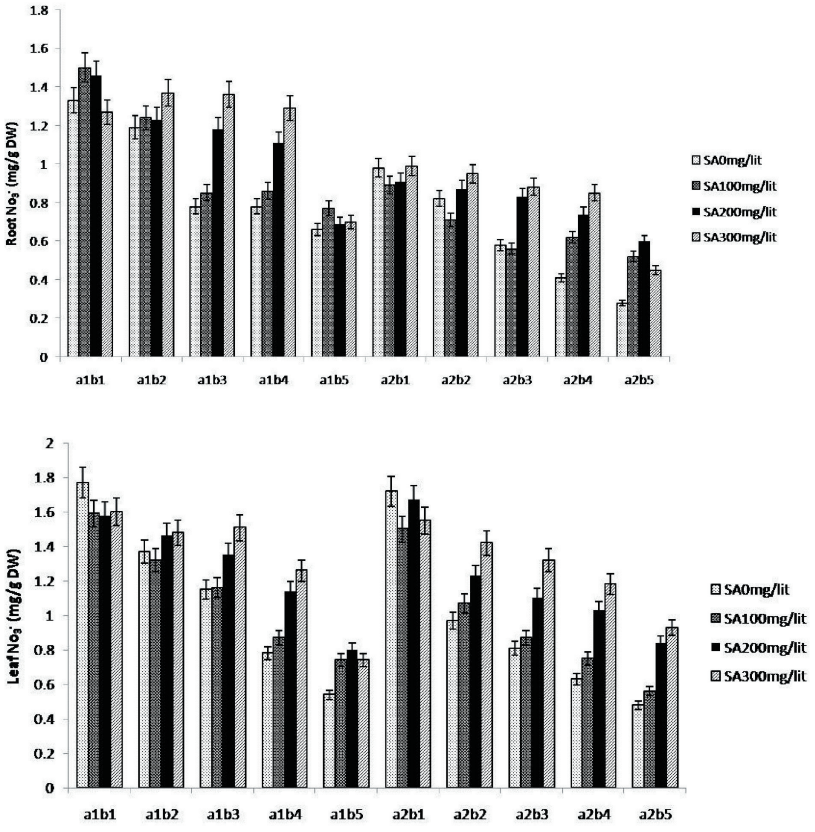

Fig. 4: Interaction of cultivar, salinity and SA on NO_3^- contents in roots and leaves of two grapevine cultivars. **a**: cultivar (a1: 'Qarah Shani', a2: 'Thompson Seedless'), **b**: salinity (b1: 0 (control), b2: 25, b3: 50, b4: 75 and b5: 100 mM).

Table

Interaction of cultivar, salinity and SA on Ca^{2+}, Mg^{2+}, Fe^{2+} and Zn^{2+} contents in roots and leaves of two grapevine cultivars

V. vinifera L.	NaCl (mM)	SA ($mg \cdot L^{-1}$)	Ca^{2+} (%)		Mg^{2+} (%)		Fe^{2+} ($mg \cdot kg^{-1}$ DW)		Zn^{2+} ($mg \cdot kg^{-1}$ DW)	
			Leaves	Roots	Leaves	Roots	Leaves	Roots	Leaves	Roots
Qarah Shani	0	0	0.878a	0.925 a	1.95 a-c	0.56 ab	308.46 ab	160.84 a-e	47.94 a-g	25.52 a-c
		100	0.836ab	0.887 a	1.99 ab	0.522 b-d	301.23 a-c	166.10 a-d	44.62 c-i	23.26 a-e
		200	0.857 ab	0.9 a	1.985 ab	0.572 a	311.01 a	167.09 a-d	49.48 a-e	26.37 ab
		300	0.822 abc	0.818 a-c	2.01 ab	0.535 abc	282.79 a-f	170.98 a-c	51.49 a-c	17.81 c-k
	25	0	0.804 b-d	0.795 a-c	2.03 a	0.53 a-d	277.87 a-h	152.65 a-f	41.03 e-j	16.77 e-k
		100	0.81 b-d	0.812a-c	1.99 ab	0.517 a-d	263.02 b-j	148.05 a-f	39.36 g-j	17.18 d-k
		200	0.838 ab	0.81 a-c	2.02 a	0.555 ab	280.34 a-g	155.49 a-f	45.96 c-h	19.29 b-i
		300	0.817 a-c	0.84 ab	2.00ab	0.512 a-e	276.87 a-i	163.70 a-d	46.49 b-h	22.33 a-e
	50	0	0.695 g-i	0.67 c-e	1.68 f-i	0.407 g-m	224.88 j-l	129.10 e-i	35.33 j	15.68 e-l
		100	0.633 j-m	0.625 d-f	1.73 e-i	0.387 h-n	239.56 f-k	139.19 c-g	36.41 ij	17.28 d-k
		200	0.767 c-e	0.83 ab	1.87 a-e	0.492 a-g	272.94 a-i	147.33 a-f	40.07 f-j	21.72 a-e
		300	0.796 b-d	0.875 a	2.00 ab	0.512 a-e	259.95 c-j	159.12 a-e	41.45 d-j	20.81 a-g
	75	0	0.642 i-m	0.552 e-h	1.73 e-i	0.36 i-o	144.05 n-p	77.36 l-o	24.97 kl	10.50 k-p
		100	0.611 k-m	0.62 d-f	1.87 a-e	0.325 l-o	146.18 n-p	88.70 j-n	19.99 k-m	13.91 g-m
		200	0.717 e-g	0.78 a-c	1.61 h-j	0.412 f-m	232.26 h-k	102.39 i-l	21.65 kl	12.70 h-m
		300	0.755d-f	0.813 a-c	1.82 b-g	0.452 c-h	242.82 e-k	114.33 g-j	26.73 k	11.45 j-o
	100	0	0.586 mn	0.431 g-k	1.54 i-k	0.270 o-r	122.51 p	60.75 m-o	19.67 k-m	4.20 op
		100	0.597 lm	0.482 f-j	1.48 j-l	0.278 o-r	142.76 n-p	57.61 n-o	20.00 k-m	3.54 p
		200	0.68 g-j	0.538 e-i	1.75 d-h	0.33 k-o	137.84 op	87.28 j-n	25.53 kl	6.72 m-p
		300	0.705 f-h	0.437 g-k	1.96 a-c	0.35 j-o	156.85 m-p	84.23 j-n	23.22 kl	5.75 n-p
Thompson Seedless	0	0	0.859 ab	0.845 ab	2.01 ab	0.47 b-h	296.00 a-d	175.01 ab	56.54 a	27.73 a
		100	0.86 ab	0.82 a-c	2.03 a	0.502 a-f	303.70 a-c	174.86 ab	55.23 ab	23.66 a-d
		200	0.877 a	0.847 ab	1.99 ab	0.512 a-e	287.69 a-e	171.42 a-c	50.37 a-d	22.28 a-e
		300	0.846 ab	0.832 ab	2.04 a	0.49 a-g	298.48 a-d	177.75 a	48.66 a-f	21.59 a-f
	25	0	0.808 b-d	0.565 d-g	1.85 a-f	0.42 e-k	234.85 g-k	126.80 f-i	37.73 h-j	19.56 b-i
		100	0.812 b-d	0.546 e-h	1.88 a-e	0.415 f-l	253.47 d-j	145.89 a-f	43.01 c-i	19.46 b-i
		200	0.766 c-e	0.598 d-f	1.93 a-d	0.445 c-i	275.52 a-i	149.24 a-f	45.17 c-i	22.17 a-e
		300	0.806 b-d	0.707 b-d	1.92 a-d	0.460 c-h	272.32 a-i	147.15 a-f	48.42 a-g	23.22 a-e
	50	0	0.647 h-l	0.378 j-m	1.65 g-j	0.342 k-o	185.13 l-n	102.06 i-l	21.93 kl	9.40 l-p
		100	0.682 g-j	0.392 i-l	1.55 i-k	0.32 m-o	199.22 k-m	112.81 h-k	25.41 kl	14.07 f-m
		200	0.674 g-j	0.445 g-j	1.63 h-j	0.277 o-r	230.71 i-k	137.16 d-h	43.49 c-i	18.15 c-j
		300	0.842 ab	0.595 d-f	1.75 d-h	0.440 d-j	259.55 c-j	143.88 b-g	39.92 f-j	19.43 b-i
	75	0	0.534 no	0.292 k-m	1.37 lm	0.297 n-p	159.81 m-p	70.18 m-o	17.22 lm	6.17 n-p
		100	0.496 o	0.267 lm	1.42 kl	0.287 o-q	172.44 m-o	66.56 m-o	20.71 k-m	12.14 i-n
		200	0.665 g-k	0.428 g-k	1.34 lm	0.332 k-o	246.13 e-j	82.95 k-n	37.39 h-j	20.13 b-h
		300	0.817 a-c	0.405 h-l	1.78 c-g	0.387 i-n	260.79 c-j	91.43 j-m	42.22 d-j	22.80 a-e
	100	0	0.434 p	0.27 lm	1.32 lm	0.200 qr	140.31 n-p	50.92 o	12.70 m	6.70 m-p
		100	0.425 p	0.243 m	1.21 m	0.227 p-r	147.32 n-p	58.61 no	17.59 lm	5.62 n-p
		200	0.515 o	0.367 j-m	1.35 lm	0.27 o-r	154.06 n-p	75.06 l-o	18.61 k-m	7.48 m-p
		300	0.527 o	0.412 h-l	1.49 j-l	0.192 r	145.18 n-p	65.40 m-o	16.54 lm	7.70 mp

Mean value followed by different letters are significantly different ($P < 0.01$).

Discussion

Plant growth is an important factor in determining its ability to tolerate salt stress and the genetic variation among plants provide a valuable tool in the selection of cultivars with desirable traits (Misra and Dwivedi 2004). The current study clearly demonstrates different responses of two grapevine cultivars when subjected to NaCl stress. Our data indicated that 'Qarah Shani' is relatively more tolerant than 'Thompson Seedless'. The results are in line with those reported by Mohammadkhani *et al*. (2013). They showed that 'Qarah Shani' was relatively salt tolerant. Salt stress inhibited shoot and root dry weights significantly; especially, in the 75 and 100 mM NaCl treatments. The results are in accordance with those reported for grapevine by Ben-Asher *et al.* (2006) and also by Shani and Ben-Gal (2005). On dry weight basis, the decrease in biomass production under salt stress conditions was less in 'Qarah Shani' as compared with 'Thompson Seedless'. The findings suggest that under salt stress, the ameliorative effects

of SA on shoot and root dry weights of the two cultivars are pronounced (data not shown); especially, in 'Qarah Shani'. Similar findings have been reported on soybean by Gutierrez-Coronado *et al.* (1998), on maize by Khodary (2004) and on cucumber by Yildirim *et al.* (2008). Munns (1993) showed that a decrease in plant biomass production due to salinity has been attributed to low external water potential, ion toxicity and ion imbalance. Generally, it seems that the main reason for the reduced plant growth in our study under NaCl stress could be due to disturbed or imbalanced inorganic nutrition. In the presence of SA, Cl^- and Na^+ uptakes were restricted that is resulted in high K^+/Na^+ ratio in roots and leaves. According to Cakmak (2005), a higher K^+/Na^+ ratio in plants is an important strategy to minimize the adverse effects of salinity on growth parameters.

Only a few experimental data have shown that SA can influence absorption of nutrients in fruit trees under salinity stress. The relations between salinity and mineral nutrition of crops species have been studied comprehensively (Grattan and Grieve 1999). Numerous reports have indicated that salinity reduces nutrients uptake and accumulation by plants (Rogers *et al.* 2003, Hu and Schmidhalter 2005).

The current results showed that with the increase in salt concentration in nutrient solution, the roots of the two studied grapevine cultivars had limited capacity in Na^+ uptake and transport to the shoots was more effective in 'Qarah Shani' than in 'Thompson Seedless' in this respect (Fig. 1). Many of the deleterious effects of Na^+ seem to be related to the cell membrane structural and functional integrity (Kurth *et al.* 1986). In plant species such as grapevine and citrus, Cl^- toxicity is more important than Na^+ toxicity. However, it does not imply that Cl^- is metabolically more toxic than Na^+ rather the studied species are more effective in excluding Na^+ from the leaf blades than Cl^- (Munns 2005). Foliar spray with salicylic acid reduced Na^+ absorption and toxicity in the current study which may be due to less damage inflicted to the cell membrane by toxic sodium ions. Cl^- concentration in leaves of salinized grapevines exceeded those in roots. The ability of 'Qarah Shani' to maintain relatively low leaf Cl^- content and to have higher biomass production at 75 and 100 mM NaCl salinity could be the main factors contributing to its more salt tolerant characteristics in comparison with 'Thompson Seedless'. According to the results of the current study (Fig. 2), it can be concluded that 'Qarah Shani' has the ability to be more effective Cl^- exclusion cultivar than the other one although the effectiveness is reduced by an increase in salt concentration.

The similarity of the hydrated ionic radii of Na^+ and K^+ makes it difficult for cell membrane transport system to discriminate between these two ions and it seems that this is the basis of Na^+ toxicity under high salinity (Blumwald 2000). Na^+ ions can be transported into cells by K^+ transporters (Parida and Das 2004). Therefore, it seems that with the SA application at different levels of NaCl, 'Qarah Shani' was a better cultivar than 'Thompson Seedless' in discriminating K^+ from Na^+. How SA increases K^+ accumulation and decreases Na^+ and Cl^- ions uptake under salinity stress is yet to be elucidated. SA is a ubiquitous signaling molecule, which can change plasma membrane properties and affect ion channel activity (Balasubramanian *et al.* 1997, Engelberth *et al.* 2001). The SA application resulted in higher K^+ and lower Na^+ concentration in cytosol by regulating the expression and activity of K^+ and Na^+ transporters and also H^+-pumps that generate the driving force for the transport. Also SA possibly maintains membrane integrity and helps in reducing the toxic effects of Na^+ and Cl^- ions (Zhu 2003).

It has been reported that SA treatment reduced the levels of Cl^- and Na^+ and then increased the K^+ content of cells and K^+/Na^+ ratio (Gunes *et al.* 2007). It can be concluded that foliar application of SA can lead to an increase in K^+ and a decrease in Na^+ accumulation in the leaves and roots.

Along with an increase in NaCl concentration in root media, the amounts of NO_3-N decreased and Cl^- content increased in roots and leaves of both cultivars and it indicated the inhibitory effects of Cl^- ions on NO_3^- uptake. The results are in agreement with those reported by Bar *et al.* (1997) and by Lea-Cox and Syvertsen (1993) who showed that the reduction in NO^-_3 uptake under salinity is associated with the antagonistic effects of Cl^- ions. Foliar spray with SA improved NO^-_3 concentration in both cultivars significantly (Fig. 4). It has been reported that salinity reduces nitrogen accumulation in plants (Parvaiz *et al.* 2013). The reduction in NO^-_3 uptake is associated with Cl^- antagonism or reduced water uptake under saline (Lea-Cox and Syvertsen 1993). The antagonism between NO^-_3 and Cl^- uptake has been demonstrated in avocado (Bar *et al.* 1997), in citrus (Bar *et al.* 1997, Cerezo *et al.* 1997), in kiwifruit (Smith *et al.* 1987) and in strawberry (Wang *et al.* 1989).

Increasing NaCl salinity caused a significant decrease in both Ca^{2+} and Mg^{2+}concentration in the leaves and roots of both cultivars. Na^+ is the only cation with a crystal ionic radius similar to Ca^{2+} (Na^+ = 0.097 nm vs Ca^{2+} = 0.099 nm) (Cramer *et al.* 1985). Calcium as an essential element is required for the maintenance of cell membrane integrity and ion-transport regulation (Cramer *et al.* 1985). At high levels of NaCl, the amounts of Ca^{2+} and Mg^{2+} were significantly lower in 'Thompson Seedless' than in 'Qarah Shani' (Table). Shi and Zhu (2008) reported that Ca^{2+} and Mg^{2+} concentration in cucumber plants decreased at high levels of $Mn^{2+}$and the addition of SA increased their transport from nutrient solutions to the plants. The inhibitory effects of NaCl salinity on $Ca^{2+}$and Mg^{2+} uptake has also been reported (Mudgal *et al.* 2010). In the current study, with less than 100 mM NaCl salinity, SA did not affect the amount of Mg^{2+} in the roots and leaves of 'Thompson Seedless' cultivar as compared with the control (Table).

It is well known that H^+-ATPase in plasma membrane plays an important role in transport of several ions (Shi and Zhu 2008), and there are reports indicating that SA could induce H^+-ATPase activity (Hayat *et al.* 2010), which could contribute to higher Ca^{2+} and Mg^{2+} absorption under salinity stress. It is known that the micronutrient absorption is generally less affected by salt stress as compared with macronutrients (El-Fouly and Salama 1999). Changes in the micronutrient concentration in plants depend on the type of crop species, the levels of macronutrients, the levels of

salinity and the plant organ (Hu and Schmidhalter 2001).

Zn^{2+} and Fe^{2+} concentration also gradually decreased in leaves and roots of both cultivars with an increase in the external salinity level (Table). Changes in Fe^{2+} and Zn^{2+} concentration in grapevine indicated that salinity stress disturbs ionic homeostasis and application of SA alleviates such disturbances.

In conclusion, one of the most detrimental effects of salt stress is to disrupt the ionic homeostasis mechanisms in plants. The results of the current study indicate that NaCl stress reduces the uptake of nutrient elements (NO^-_3, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+} and Zn^{2+}) while Na^+ and Cl^- uptakes increase. Cl^- accumulation was more pronounced in the leaves in comparison with the roots. SA reduced Na^+ and Cl^- concentration in root and shoot of both cultivars under salinity. However, it increased NO^-_3, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+} and Zn^{2+} concentration in the tissues. SA treatments increased the K^+/Na^+ ratios in both roots and leaves. The current findings indicate that increasing mineral nutrient uptake by SA application under salinity may be one of the major mechanisms by which SA alleviates deleterious effects of salt stress on plants. The effectiveness of SA in inducing tolerance against salt stress might depend on the concentration of SA, salinity intensity and plant cultivar.

References

Al-Hakimi, A. M. A.; Hamada, A. M.; 2001: Counteraction of salinity stress on wheat plants by grain soaking in ascorbic acid, thiamin or sodium salicylate. Biol. Plant. **44**, 253-261.

Aly, S. S. M.; Soliman, S. M.; 1998: Impact of some organic acids on correcting iron chlorosis in two soybean genotypes grown in calcareous soil. Nutr. Cycl. Agro. **51**, 185-191.

Balasubramanian, S. V.; Straubinger, R. M.; Morris, M. E; 1997: Salicylic acid induces changes in the physical properties of model and native kidney membrane. J. Pharm. Sci. **86**, 199-204.

Bar, Y.; Apelbaum, A.; Kafkafi, U.; Goren, R; 1997: Relationship between chloride and nitrate and its effect on growth and mineral composition of avocado and citrus plants. J. Plant Nutr. **20**, 715-731.

Ben-Asher, J.; Tsuyuki, I.; Bravdo, B. A.; Moshe Sagih, M.; 2006: Irrigation of grapevine with saline water: I. leaf area index, stomatal conductance, transpiration and photosynthesis. Agric. Water Manage. **83**, 13-21.

Blumwald, E.; 2000: Sodium transport and salt tolerance in plants. Curr. Opin. Cell Biol. **12**, 431-434.

Borsani, O.; Valpuestan, V.; Botella, M. A.; 2001: Evidence for a role of salicylic acid in the oxidative damage generated by NaCl and osmotic stress in *Arabidopsis* seedlings. Plant Physiol. **126**, 1024-1030.

Cakmak, I.; 2005: The role of potassium in alleviating detrimental effects of abiotic stresses in plants. J. Plant Nutr. Soil. Sci. **168**, 521-530.

Cataldo, D. A.; Haroon, M.; Schrader, L. E.; Young, V. L.; 1975: Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. Soil Sci. Plant Anal. **6**, 71-80.

Cerezo, M.; Garcia-Agustin, P.; Serna, M. D.; Primo-Millo, E.; 1997: Kinetics of nitrate uptake by citrus seedlings and inhibitory effects of salinity. Plant Sci. **126**, 105-112.

Cramer, G. R.; Lauchli, A.; Polito, V. S.; 1985: Displacement of Ca^{2+} by Na^+ from the plasmalemma of root cells. Plant Physiol. **79**, 207-211.

Cramer, G. R.; Ergul, A.; Grimplet, J.; Tillett, R. L.; Tattersall, E. A. R.; Bohlman, M. C.; Vincent, D.; Sonderegger, J.; Evans, J.; Osborne, C.; Quilici, D.; Schlauch, K. A.; Schooley, D. A.; Cushman J. C.; 2007: Water and salinity stress in grapevines: early and late changes in transcript and metabolite profiles. Funct. Int. Genomics **7**, 111-134.

El-Fouly, M. M.; Salama, Z. H.; 1999: International Symposium: Nutrient Management under Salinity and Water Stress. Technion-ITT Haifa.

El-Tayeb, M. A.; 2005: Responses of barely grains to the interactive effect of salinity and salicylic acid. Plant Growth Regul. **45**, 215-224.

Engelberth, J.; Koch, T.; Schuler, G.; Bachmann, N.; Rechtenbach, Y.; Boland, W.; 2001: Ion channel forming alamethicin is potent elicitor of volatile biosynthesis and tendril coiling. Cross talk between jasmonate and salicylate signaling in lima bean. Plant Physiol. **125**, 369-377.

Fisarakis, I.; Chartzoulakis, K.; Stavrakas, D.; 2001: Responses of sultana vines (*V. vinifera* L.) on six rootstocks to NaCl salinity exposure and recovery. Agric.Water Manag. **51**, 13-27.

Gharsa, M. A. Parre, E.; Debez, A.; Bordenave, M.; Richard, L.; Leport, L.; Bouchereau, A.; Savoure, A.; Abdelly, C.; 2008: Comparative salt tolerance analysis between *Arabidopsis thaliana* and *Thellungiella halophila*, with special emphasis on K^+/Na^+ selectivity and proline accumulation. J. Plant Physiol. **165**, 588-599.

Grattan, S.; Grieve, C.; 1999: Salinity mineral nutrient relations in horticultural crops. Sci. Hortic. **78**, 127-157.

Gunes, A.; Inal, A.; Alpaslan, M.; Cicek, N.; Guneri, E.; Eraslan, F.; Guzelordo, T.; 2005: Effects of exogenously applied salicylic acid on the induction of multiple stress tolerance and mineral nutrition in maize (*Zea mays* L.). Arch. Agro. Soil Sci. **51**, 687-695.

Gunes, A.; Inal, A.; Alpaslan, M.; Eraslan, F.; Bagci, E.G.; Cicek, N.; 2007: Salicylic acid induced changes on some physiological parameters symptomatic for oxidative stress and mineral nutrition in maize (*Zea mays* L.) grown under salinity. J. Plant Physiol. **164**, 728-736.

Gutierrez-Coronado, M.; Trejo, C.; Larque-Saaverda, A.; 1998 : Effects of salicylic acid on growth of roots and shoots in soybean. Plant Physiol. Biochem. **36**, 563-565.

Hayat, Q.; Hayat, S.; Irfan, M.; Ahmad, A.; 2010: Effect of exogenous salicylic acid under changing environment: a review. Environ. Exp. Bot. **68**, 14-25.

Hoagland, D. R.; Arnon, D. S.; 1950: The water culture method for growing plants without soil. Cal. Agric. Exp. Stat. Circ. **374**, 305-311.

Hu, Y.; Schmidhalter, U.; 2001: Effects of salinity and macronutrient levels on micronutrients in wheat. J. Plant Nutr. **24**, 273-181.

Hu, Y.; Schmidhalter, U.; 2005: Drought and salinity: comparison of their effects on mineral nutrition of plants. J. Plant Nutr. Soil Sci. **168**, 541-549.

Khodary, S.; 2004: Effect of salicylic acid on the growth, photosynthesis and carbohydrate metabolism in salt stressed maize plants. Int. J. Agric. Biol. **6**, 5-8.

Kok, D.; 2012: Impacts of different salicylic acid doses on salinity tolerance of grapevine rootstocks. J. Tekirdag Agric. Fac. **9**, 32-40.

Kurth, E.; Cramer, G.; Lauchli, A.; 1986: Effects of NaCl and $CaCl_2$ on cell enlargement and cell production in cotton roots. Plant Physiol. **82**, 1102-1106.

Lea-Cox, J. D.; Syvertsen, J. P.; 1993: Salinity reduces water use and nitrate-N use efficiency of citrus. Ann. Bot. **72**, 47-54.

Misra, N.; Dwivedi, U.; 2004: Genotypic difference in salinity tolerance of green gram cultivars. Plant Sci. **166**, 1135-1142.

Mohammadkhani, N.; Heidari, R.; Abbaspour, N.; Rahmani, F.; 2013: Comparative study of salinity effects on ionic balance and compatible solutes in nine Iranian table grape (*Vitis vinifera* L.) genotypes. J. Int. Vigne Wine **47**, 99-114.

Mudgal, V.; Madaan, N.; Mudgal, A.; 2010: Biochemical Mechanisms of salt tolerance in plants. Int. J. Bot. **6**, 136-143.

Munns, R.; 1993: Physiological processed limiting plant growth, in saline soils: some dogmas and hypotheses. Plant Cell Environ. **16**, 15-24.

Munns, R.; 2005: Genes and salt tolerance: bringing them together. New Phytol. **167**, 645-663.

Munns, R.; Tester, M.; 2008: Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. **59**, 651-681.

Parida, A. K.; Das, A. B.; 2004: Salt tolerance and salinity effects on plants. Ecotoxicol. Environ. Saf. **60**, 324-341.

Parvaiz, A.; Azooz, M. M.; Prasad, M. N. V.; 2013: Ecophysiology and Responses of Plants under Salt Stress. Springer.

Parvaiz, A.; Satyawati, S.; 2008: Salt stress and phyto-biochemical responses of plants- a review. Plant Soil Environ. **54**, 89-99.

Prior, L. D.; Grieve, A. M.; Cullis, B. R.; 1992: Sodium chloride and soil texture interactions in irrigated field grown sultana grapevines. II. Plant mineral content, growth and physiology. Aust. J. Agric. Res. **43**, 1067-1083.

Raskin, I.; 1992: Salicylate, a new plant hormone. Plant Mol. Biol. **43**, 439-463.

Rogers, M.; Grieve, C.; Shannon, M.; 2003: Plant growth and ion relations in Lucerne (*Medicago sativa* L.) in response to the combined effects of NaCl and P. Plant Soil. **253**, 187-194.

Stevens, R. M.; Harvey, G.; Partington, D. L.; Coombe, B. G.; 1999: Irrigation of grapevines with saline water at different growth stages: effects on soil, vegetative growth and yield. Aust. J. Agric. Res. **50**, 343-355.

Shani, U.; Ben-Gal, A.; 2005: Long-term response of grapevines to salinity: osmotic effects and ion toxicity. Am. J. Enol. Vitic. **56**, 148-154.

Shi, Q.; Zhu, Z.; 2008: Effects of exogenous salicylic acid on manganese toxicity, element content and antioxidative system in cucumber. Environ. Exp. Bot. **63**, 317-326.

Smith, G. S.; Clark, C. J.; Holland, P. T.; 1987: Chlorine requirement of kiwifruit (*Actinidia deliciosa* L.). New Phytol. **106**, 71-80.

Walker, R. R.; Blackmore, D. H.; Clingeleffer, P. R.; Correll, R. L.; 2002: Rootstock effects on salt tolerance of irrigated field-grown grapevines (*Vitis vinifera* L. cv. Sultana). I. Yield and vigor inter relationships. Aust. J. Grape Wine Res. **8**, 3-14.

Wang, D. Q.; Guo, B. C.; Dong, X. Y.; 1989: Toxicity effects of chloride on crops. Chinese J. Soil Sci. **30**, 258-261.

Wang, L. J.; Li, S. H.; 2006: Salicylic acid induced heat or cold tolerance in relation to Ca^{2+} homeostasis and antioxidant systems in young grape plants. Plant Sci. **170**, 685-694.

Yildirim, E.; Turan, M.; Guvene, I.; 2008: Effect of foliar salicylic acid applications on growth, chlorophylle and mineral content of cucumber grown under salt stress. J. Plant Nutr. **31**, 593-612.

Zhu, J. K.; 2003: Regulation of ion homeostasis under salt stress. Curr. Opin. Plant Biol. **6**, 441-445.

Received December 9, 2013