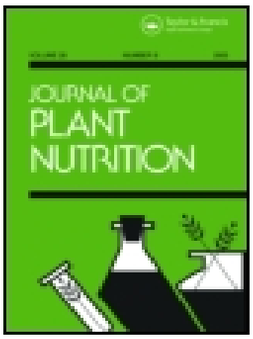

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Effect of Foliar Salicylic Acid Applications on Growth, Chlorophyll, and Mineral Content of Cucumber Grown Under Salt Stress

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ABSTRACT

The objective of this study was to determine the effect of foliar salicylic acid (SA) applications on growth, chlorophyll, and mineral content of cucumber grown under salt stress. The study was conducted in pot experiments under greenhouse conditions. Cucumber seedlings were treated with foliar SA applications at different concentrations (0.0, 0.25, 0.50, and 1.00 mM). Salinity treatments were established by adding 0, 60, and 120 mM of sodium chloride (NaCl) to a base complete nutrient solution. The SA was applied with spraying two times as before and after transplanting. Salt stress negatively affected the growth, chlorophyll content and mineral uptake of cucumber plants. However, foliar applications of SA resulted in greater shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight as well as higher plants under salt stress. Shoot diameter and leaf number per plant increased with SA treatments under salt stress. The greatest chlorophyll content was obtained with 1.00 mM SA treatment in both saline and non-saline conditions. Leaf water relative content (LWRC) reduced in response to salt stress while SA raised LWRC of salt stressed cucumber plants. Salinity treatments induced significant increases in electrolyte leakage. Plants treated with foliar SA had lower values of electrolyte leakage than non-treated ones. In regard to nutrient content, it can be interfered that foliar SA applications increased almost all nutrient content in leaves and roots of cucumber plants under salt stress. Generally, the greatest

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values were obtained from 1.00 mM SA application. Based on these findings, the SA treatments may help alleviate the negative effect of salinity on the growth of cucumber.

Keywords: cucumber, salt stress, salicylic acid, growth, chlorophyll, mineral content

INTRODUCTION

Salinity is a major environmental constraint to crop productivity throughout the arid and semi arid regions of the world. High concentrations of salts in soils account for large decreases in yield of a wide variety of crops all over the world. Globally, more than 770,000 km^2 of land is salt-affected by secondary salinization: 20% of irrigated land, and about 2% of dryland agricultural land (FAO, 2000). Salt stress affects many aspects of plant metabolism and, as a result, growth and yields are reduced. Excess salt in the soil solution may adversely affect plant growth either through osmotic inhibition of water uptake by roots or specific ion effects. Specific ion effects may cause direct toxicity or, alternatively, the insolubility or competitive absorption of ions may affect the plant's nutritional balance (Greenway and Munns, 1980; Turan and Aydın, 2005). Salinity has been shown to increase the uptake of Na or decrease the uptake of Ca and K (Neel et al., 2002; Yildirim et al., 2006a). In many crop plants, seed germination and early seedling growth are the most sensitive stages to environmental stresses such as salinity (Sivritepe et al., 2003; Yildirim and Guvenc, 2006). Therefore, salinity is one of the most significant abiotic factors limiting crop productivity (Munns, 2002).

One of the most effective ways to overcome salinity problems is the introduction of salt-tolerant crops (Foolad and Lin, 1997). Breeding for tolerance to salinity in crops has usually been limited by a lack of reliable traits for selection. Multiple genes seem to act in concert to increase salinity tolerance, and certain proteins involved in salinity stress protection have also been recognized (Murillo-Amador et al., 2006). Therefore, the development of methods and strategies to ameliorate deleterious effects of salt stress on plants has received considerable attention.

Salicylic acid (SA) has been shown as an important signal molecule for modulating plant responses to environmental stress (Bergmann et al., 1994; Breusegem et al., 2001). Exogenous application of SA may influence a range of diverse processes in plants, including seed germination (Korkmaz, 2005), stomatal closure, ion uptake and transport (Gunes et al., 2005), membrane permeability (Barkosky and Einhellig, 1993), and photosynthetic and growth rate (Khan et al., 2003). In addition to facilitating the growth of plant, SA has been shown to play a role in mitigating the deleterious effects of some environmental stresses including low temperature on pepper (Korkmaz, 2005), high temperature and drought on cucumber, bean, tomato and wheat (Singh

and Usha, 2003; Senaratna et al., 2000; Shi et al., 2006), heavy metal on medic (Drazic et al., 2006), and phytopathogens (Segarra et al., 2006).

Enhancing stress tolerance in plants has major implications in agriculture and horticulture (Senaratna et al., 2000). The ameliorative effects of SA has been well documented in inducing salt tolerance when applied as a soil drench (Senaratna et al. 2000; Stevens et al., 2006) in bean and tomato, addition to hydroponic culture (Tari et al., 2002; Szepsi et al., 2005) in tomato, seed treatment (Senaratna et al., 2000; El-Tayeb, 2005; Gunes et al., 2005) in bean, tomato, barley and maize, and foliar (Aldesuquy et al., 1998) in wheat. Cucumber is an important vegetable crop for human nutrition in the world, and plant growth has been reported to be sensitive to salt stress (Alpaslan and Gunes, 2001; Stepien and Klobus, 2006). To the authors' knowledge, the effect of foliar SA applications on growth and nutrient uptake of cucumber under salt stress conditions has not been studied. Therefore, an experiment was conducted to determine if foliar SA applications could confer resistance in cucumber plants to salt stress. This paper focuses on the effect of foliar SA applications with different concentrations on plant growth, chlorophyll and mineral content of cucumber grown under salt stress.

MATERIAL AND METHODS

Plant Materials

The study was conducted at Atatürk University, under greenhouse conditions in Turkey in 2006. Cucumber (*Cucumis sativus* L cv 'Gordion F1') plants were maintained under natural light conditions, approximate a day/night temperature of 28/20°C and 70% relative humidity during the span of the experiment. Cucumber seeds were sown into plastic trays filled with peat [pH:5.5, EC:250 mmhos/cm, nitrogen (N):300 mg/L, phosphorus (P_2O_5): 300 mg/L, potassium (K_2O): 400 mg/L, organic matter: 2%]. Trays were 53 × 33 cm, with 45 cells (5 cm × 6 cm). Healthy and homogenous seedlings were transferred to free draining pots (20 and 17 cm top and bottom diameter respectively, and 20-cm height, with holes in the bottom) filled with mixture of peat:vermiculite (1:1, v:v) after 25 days after sowing (DAS). All pots were randomized on the benches in the greenhouse. There were 3 replicates per treatment and 8 plants per replicates.

Spray Treatments

Salicylic acid (SA; 2-hydroxybenzoic acid), obtained from Sigma Chemical Co. UK, were initially dissolved in 100 μL dimethyl sulfoxide and concentrations of 0.25, 0.50, and 1.00 mM (pH 6.0–6.5) were made up with distilled water containing 0.02% Tween 20 (Polyoxyethylenesorbitan monolaurate, Sigma

Chemicals, UK) (Khan et al., 2003). The initial foliar SA treatment occurred after 20 DAS when the seedlings had 2–3 true leaves. Lower leaf surface was sprayed until wetted as well as upper surface since it was reported that absorption by the lower leaf surface was rapid and effective (Hull et al., 1975). A subsequent application was made 5 days after transplanting. The SA was sprayed with the solutions until dripping, with a held atomizer. Plants sprayed with 0.02% Tween 20 served as the control.

Salt (NaCl) Treatments

Salinity treatments were established by adding 0, 60, and 120 mM of NaCl to a base complete nutrient solution (SoFertig) when the seedlings transplanted. The composition of the SoFertig (Elfatochem Co., Paris, France) was (%): N, 17; P_2O_5, 9; K_2O, 31; magnesium (Mg), 2; sulphate (SO_4), 4; sodium (Na), 0.001; iron (Fe), 0.02; zinc (Zn), 0.002; copper (Cu), 0.002; boron (B), 0.01; manganese (Mn), 0.01; molybdenum (Mo), 0.001. The solution was prepared by adding SoFertig to the distilled water. The electrical conductivities of these solutions after adding 0, 60, and 120 mM of NaCl were determined with a conductivity meter, Model 470 (Jenway Limited). Electrical conductivities (EC) of these solutions were 1.86 dS m^{-1} for 0 mM NaCl, 8.24 dS m^{-1} for 60 mM NaCl, and 14.02 dS m^{-1} for120 mM NaCl.

Chlorophyll Measurements

A portable chlorophyll meter (SPAD–502, Konica Minolta Sensing, Inc., Japan) was used to measure leaf greenness of the cucumber plants at 2 days before harvest. For each plant measurements were taken at four locations on each leaf, two on each side of the midrib on all fully expanded leaves and then averaged (Khan et al., 2003).

Measurement of Electrolyte Leakage (Membrane Permeability)

For measurement of electrolyte leakage, 20 leaf discs (10 mm in diameter) from the young fully expanded leaves from two plants per replicate were placed in 50 mL glass vials, rinsed with distilled water to remove electrolytes released during leaf disc excision. Vials were then filled with 30 mL of distilled water and allowed to stand in the dark for 24 h at room temperature. Electrical conductivity (EC1) of the bathing solution was determined at the end of incubation period. Vials were heated in a temperature-controlled water bath at 95°C for 20 min, and then cooled to room temperature and the electrical conductivity (EC2) was measured. Electrolyte leakage was calculated as percentage of EC1/EC2 (Shi et al., 2006).

Leaf Relative Water Content (LRWC)

Two leaves were collected from the young fully expanded leaves of two plants per replicate. Individual leaves first detached from the stem and then weighed to determine fresh weight (FW). In order to determine turgid weight (TW), leaves were floated in distilled water inside a closed petri dish. Leaf samples were weighed periodically, after gently wiping the water from the leaf surface with the tissue paper until a steady state achieved. At the end of imbibition period, leaf samples were placed in a pre-heated oven at 80°C for 48 h, in order to determine dry weight (DW). Values of FW, TW, and DW were used to calculate LRWC using the equation below (Kaya et al., 2003):

$$\text{LRWC}(\%) = [(\text{FW} - \text{DW})/(\text{TW} - \text{DW})] \times 100$$

Growth Parameters

25 days after transplanting (50 DAS), four plants from each replicate were harvested, and data on plant growth variables, such as shoot fresh weight, root fresh weight, plant height, shoot diameter, shoot dry weight, root dry weight, and leaf number were collected. The plant material for dry weight was dried at 70°C for two days.

Mineral Analysis

In order to determine the mineral contents of shoot and root, plants samples were oven-dried at 70°C for 48 h and then ground. The micro-Kjeldahl procedure was applied for determination of N. Potasium (K), calcium (Ca), and Mg contents were determined after wet digestion of dried and ground sub-samples in a sulphuric acid (H_2SO_4)-Se-salisilic acid mixture. In the diluted digests, P, and sulphur (S) were measured spectrophotometrically by the indophenol-blue method and barium sulphate method with a spectrophotometer at 660 nm and at 440 nm respectively after reaction with ascorbic acid. K and Ca contents of plants were determined by flame photometry. Mg, Na, Fe, Mn, Zn, and Cu contents were determined by atomic absorption spectrometry using the method of AOAC (1990).

Statistical Analysis

The statistical analysis was conducted using the GLM procedure of SAS (SAS, 1985). Experimental design was hierarchical with respect to two factors arranged in a completely randomized design with three replications. The first factor (NaCl levels) had three levels (0, 60 and 120 mM), and the second one

(SA treatments) had four levels (0.00, 0.25, 0.50, 1.00 mM) (3 × 4 factorial experimental design). Data were subjected to analysis of variance (ANOVA) to compare the effects of salt stress treatments and SA treatments. The differences between the means were compared using least significant difference test (LSD, $P < 0.05$).

RESULTS AND DISCUSSION

Growth

Shoot fresh weight, shoot dry weight, root fresh weight and root dry weight of cucumber seedlings were found to significantly decrease as the salt concentration was raised. Foliar SA applications increased significantly these parameters compared to the control under both absence and presence salt stress. 1.00 mM SA application under salt stress gave the higher values for these parameters than the other treatments (Fig. 1).

External NaCl salinity up to 120 mM decreased shoot diameter of cucumber plants. Plants treated with foliar SA showed greater shoot diameter than non-treated plants (control). The greatest shoot diameter was obtained by 0.50 and 1.00 mM SA in 60 mM NaCl concentration and all SA treatments in 120 mM (Fig. 1).

Plant height decreased dramatically with the increasing NaCl concentration. All SA treatments increased the plant height compared to non-treated plants both in absence and presence of salinity. Plants treated with 1.00 mM SA had the highest plant height at 60 and 120 mM of NaCl (Fig. 1). Similar to plant height of cucumber seedlings, leaf number decreased with the increasing NaCl concentration. All SA treatments affected positively leaf number compared to control under salt stress (Fig. 2).

Chlorophyll

Chlorophyll was significantly affected by salinity and SA treatments. Chlorophyll reading values were significantly decreased with the increasing salinity stress. However, foliar SA applications used in the study caused to the elevated reading values. The highest reading values were obtained from 1.00 mM SA application in all NaCl treatments (Fig. 2).

Leaf Relative Water Content (LRWC)

Increasing the concentrations of NaCl from 0 to 120 mM lowered LRWC in cucumber plants; however, foliar SA applications gave the increased LRWC compared to control plants under salt stress. The maximum LRWC values

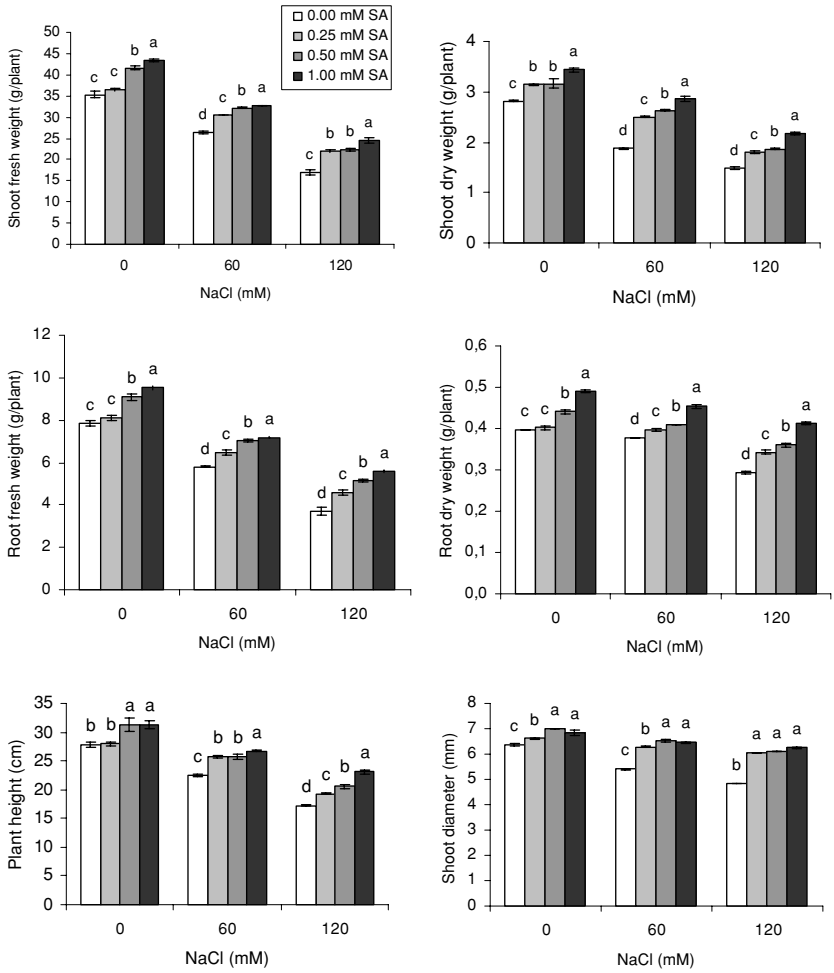

Figure 1. Shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, plant height and shoot diameter of cucumber seedlings in response to foliar SA applications under salt stress. Different letters on top of bars indicate significant differences according to LSD test ($p < 0.05$) at each salt level. Vertical bars indicate the mean $\pm$ SE.

observed with the 0.50 and 1.00 mM SA in 60 mM of NaCl, and with the 1.00 mM SA in 120 mM of NaCl (Fig. 2).

Electrolyte Leakage

Salinity treatments induced significant increases in electrolyte leakage compared to control (0 mM NaCl). Plants treated with foliar SA had lower values

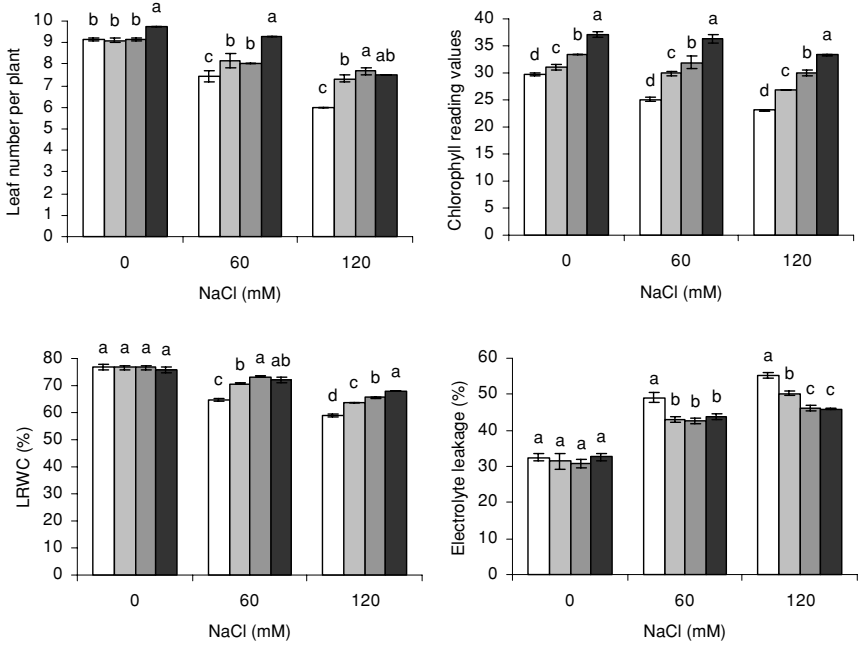

Figure 2. Leaf number per plant, chlorophyll content, electrolyte leakage and LRWC of cucumber seedlings in response to foliar SA applications under salt stress. Different letters on top of bars indicate significant differences according to LSD test ($p < 0.05$) at each salt level. Vertical bars indicate the mean ± SE.

than non-treated ones. The 0.50 and 1.00 mM SA application lowered electrolyte leakage compared to the other treatments under high salt stress. There were no significant differences between treatments in regard to electrolyte leakage under salt absence (Fig. 2).

Mineral Concentrations of Plants' Parts

The concentrations of some macro and micro plant nutrient content in cucumber leaves and roots in response to the foliar SA applications are given in Tables 1 and 2. External NaCl salinity up to 120 mM decreased the mineral content in shoot and root of cucumber plants except Na content regardless of SA treatments. Salt stress increased the concentration of Na in leaves and roots of cucumber. However, increasing concentration of SA significantly decreased the Na content in both organs compared to the control. Plants treated with foliar SA often showed greater mineral content in leaves and roots of cucumber than the non-treated plants. Generally the greatest values were obtained from 1.00 mM

Table 1
Effect of foliar SA treatments on mineral content in leaves of cucumber under salt stress

Salt treatment (mM)	SA treatment (mM)	N %	P %	K %	Ca %	Mg %	S %	Na mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg	Cu mg/kg
0	0	3.45 c[z]	0.53 c[z]	4.25	1.84	0.68	0.42 b[z]	65 a[z]	138 c[z]	54 c[z]	27	27
	0.25	3.54 c	0.54 bc	4.11	1.85	0.63	0.54 a	66 a	150 b	64 bc	30	30
	0.50	4.38 b	0.58 b	4.07	1.74	0.63	0.57 a	58 b	152 b	73 b	28	28
	1.00	4.93 a	0.67 a	4.36	1.87	0.67	0.57 a	58 b	158 a	86 a	30	30
	LSD	0.20	0.05	n.s	n.s	n.s	0.03	2.31	5.04	10.65	n.s	n.s
60	0	3.35 c[z]	0.35 c[z]	3.23 b[z]	1.31 c[z]	0.56 b[z]	0.23 b[z]	198 a[z]	65 b[z]	42 c[z]	76	21 c[z]
	0.25	3.73 b	0.38 bc	3.62 a	1.49 b	0.59 a	0.23 b	163 b	60 b	45 c	70	22 bc
	0.50	3.87 b	0.48 b	3.72 a	1.62 a	0.60 a	0.27 a	110 c	68 b	59 b	72	24 b
	1.00	4.69 a	0.63 a	3.83 a	1.64 a	0.59 a	0.29 a	62 d	89 a	75 a	76	27 a
	LSD	0.35	0.10	0.32	0.08	0.02	0.04	12.39	15.17	6.59	n.s	2.82
120	0	2.85 c[z]	0.35 b[z]	3.08 c[z]	1.28 b[z]	0.53 b[z]	0.20	236 a[z]	56 b[z]	38 b[z]	68	14 b[z]
	0.25	3.04 bc	0.39 a	3.31 b	1.34 ab	0.56 a	0.22	230 a	56 b	40 b	68	15 b
	0.50	3.35 ab	0.39 a	3.35 b	1.34 ab	0.55 ab	0.23	168 b	68 a	47 a	71	18 a
	1.00	3.74 a	0.39 a	3.64 a	1.38 a	0.57 a	0.24	87 c	75 a	45 a	73	19 a
	LSD	0.38	0.02	0.21	0.05	0.02	n.s	24.98	9.69	4.31	n.s	2.75

[z]Numbers with the same letters in the same column are not statistically different ($P < 0.05$).
n.s: non significant.

Table 2
Effect of foliar SA treatments on mineral content in roots of cucumber under salt stress

Salt treatment (mM)	SA treatment (mM)	N %	P %	K %	Ca %	Mg %	S %	Na mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg	Cu mg/kg
0	0	1.35 b[z]	0.19 c[z]	1.31 b[z]	0.31 b[z]	0.29 c[z]	0.13	73	129 d[z]	120	131 d[z]	53 c[z]
	0.25	1.43 a	0.29 b	1.34 b	0.34 b	0.30 bc	0.13	66	142 c	112	143 c	57 bc
	0.50	1.42 a	0.32 a	1.35 b	0.35 a	0.31 ab	0.13	67	162 b	116	159 b	64 b
	1.00	1.44 a	0.34 a	1.42 a	0.35 a	0.33 a	0.14	65	175 a	127	186 a	73 a
	LSD	0.04	0.03	0.05	0.03	0.02	n.s	n.s	6.54	n.s	10.37	7.41
60	0	0.86 c[z]	0.12 c[z]	1.13 c[z]	0.21 c[z]	0.28 b[z]	0.11	358 a[z]	111 b[z]	95 b[z]	131 b[z]	43 b[z]
	0.25	1.07 b	0.13 c	1.23 b	0.25 b	0.30 ab	0.13	210 b	115 b	96 b	140 a	49 ab
	0.50	1.18 ab	0.17 b	1.23 b	0.27 ab	0.28 b	0.12	171 c	130 a	99 b	141 a	53 a
	1.00	1.30 a	0.20 a	1.30 a	0.28 a	0.34 a	0.12	112 d	139 a	110 a	146 a	55 a
	LSD	0.13	0.02	0.06	0.03	0.04	n.s	12.89	12.23	8.51	6.24	7.09
120	0	0.77 c[z]	0.11 c[z]	1.18 b[z]	0.19 b[z]	0.21 b[z]	0.10	398 a[z]	122 b[z]	93 bc[z]	122 c[z]	33 c[z]
	0.25	0.77 c	0.13 bc	1.30 a	0.20 b	0.22 b	0.11	372 b	123 b	92 c	131 bc	36 bc
	0.50	0.91 b	0.16 a	1.34 a	0.24 a	0.24 a	0.12	264 c	136 a	96 ab	134 b	39 ab
	1.00	1.02 a	0.15 ab	1.30 a	0.25 a	0.25 a	0.12	192 d	137 a	98 a	144 a	44 a
	LSD	0.08	0.02	0.06	0.02	0.02	n.s	23.82	7.90	3.46	10.10	4.72

[z] Numbers with the same letters in the same column are not statistically different ($P < 0.05$).
n.s: non significant

SA application for both plant organs. The SA did not affect the concentration of Zn in leaves of cucumber under both presence and absence salinity.

Greater N, P, S, Fe, and Mn contents were observed in leaves of cucumber treated with SA under salt absence while K, Ca, Mg, Zn, and Cu contents were not affected by SA treatments. Moreover, elevated foliar SA applications caused the increased mineral content in cucumber roots except S, Na, and Mn.

Saline soils and saline irrigations constitute a serious production problem for vegetable crops as saline conditions are known to suppress plant growth (Shannon and Grieve, 1999). The present study demonstrates salinity adversely affected the growth of cucumber regardless of SA treatments. Earlier studies have shown that 25, 50, 100 and 190 mM NaCl treatments decreased the some growth parameters such as fresh and dry weight in shoot and root of cucumber plants (Chartzoulakis, 1994; Zhu et al., 2004). However, foliar SA applications off-set the negative impact of salinity on growth of cucumber in the study. The SA applications increased the fresh and dry weight of shoot and root, leaf number, shoot diameter, plant height of cucumber seedlings compared to the control under salt stress. Plants treated with 1.00 mM SA had usually the highest growth parameters followed by 0.50 mM SA. 1.00 mM SA produced greater shoot fresh weight, shoot dry weight, root fresh weight and root dry weight up to 23%, 53%, 24%, and 19% in 60 mM NaCl than that of the control. In 120 mM NaCl, an increase of 44%, 46%, 51%, and 40% was observed in shoot fresh weight, shoot dry weight, root fresh weight, and root dry weight of cucumber plants compared to the control. These results are in agreement with those of Shakirova et al. (2003) in wheat, El-Tayeb (2005) in barley, Stevens et al. (2006) and Szepsi et al. (2005) in tomato, and Khodary (2004) and Gunes et al. (2006) in maize who showed that SA treatments ameliorated the negative effects of salt stress on fresh and dry weight of plants. Shakirova et al. (2003) indicated that SA treatments reduced the damaging action of salinity on wheat seedling growth, raising indoleacetic acid content and enhancing of cell division and extension of root cells. Khan et al. (2003) reported that SA stimulated the root formation of some crops. Gunes et al. (2006) recorded that increases in dry matter of salt stressed plants in response to SA might be related to the induction of antioxidant response and protective role of membranes that increase the tolerance of plant to damage. Furthermore, it has been reported that SA applications increase carbon dioxide (CO_2) assimilation and photosynthetic rate, thus increasing dry matter (Khan et al., 2003; Fariduddin et al., 2003; Szepsi et al., 2005). This increase in dry matter content might also be attributed to the increased mineral uptake by stressed plant with SA treatment. In the study, it was determined that foliar SA applications increased the growth parameters of cucumber seedlings compared to the control under absence of salinity. Similar findings were reported by Yildirim et al. (2006b) for cucumber and Gutierrez-Coronado et al. (1998) and Lian et al. (2000) for soybean, which foliar SA applications positively affected shoot and root growth parameters.

It has been reported that SPAD-502 chlorophyll meter can estimate total chlorophyll amounts in leaves of a variety of species with a high degree of accuracy, which is a non-destructively method (Neufeld et al., 2006). Increasing salinity level decreased the SPAD reading values in cucumber leaves. These observations are consistent with those of Downton et al. (1985), Shim et al. (2003), and Stepien and Klobus (2006) who indicated that chlorophyll content considerably decreased in the leaves of spinach and cucumber plants with increasing NaCl concentration. Parida and Das (2005) reported that salt stress inhibited the chlorophyll and total carotenoid contents in the leaves of many crops. In the current study, SA treated plants showed greater SPAD reading values than non-treated plants. These results support those of El-Tayeb (2005) and Gunes et al. (2006). They proved that SA treatments caused to the increased chlorophyll content of leaves of barley and maize under salt stress. Khodary (2004) determined also that foliar SA treatments raised chlorophyll a, b, and carotenoids content, increasing the rate of photosynthesis under salt stress. Tari et al. (2002) found out that SA reduced the salt stress-induced loss in chlorophyll content of leaves of tomato plants. The results of this study showed that SA applications also increased SPAD reading values under salt stress absence. Our results agreed with also those of Ghai et al. (2002) in rutabaga, Moharekar et al (2003) in wheat and Yildirim et al. (2006b) in cucumber that showed a consistently higher chlorophyll content of plant leaves with SA application. Furthermore, Shi et al. (2006) indicated that foliar 1.00 mM SA increased the chlorophyll content of cucumber seedlings grown under heat stress.

The LRWC is a useful measure of the physiological water status of plants (Gonzalez and Gonzalez-Vilar, 2001). Water stress often results when plants are subject to high salt concentrations. Salt stress reduced LRWC in the leaves of cucumber seedlings grown at 60 and 120 mM NaCl. Similar observations were made by Chartzoulakis (1994) and Stepien and Klobus (2006) who found out that NaCl caused reduction in the relative water content in the leaves of cucumber seedlings. The SA treatments induced an increase in LRWC of the stressed plants compared to the non-treated plants. El-Tayeb (2005) reported that plants from seeds with treated 1.00 mM SA had higher relative water content than the control plants under salinity. Similarly, Tari et al. (2002) and Szepsi et al. (2005) found that exogenous SA treatment increased water potential and relative water content of leaves of salt stressed tomato plants. This phenomenon may be attributed that foliar SA application can increase leaf diffusive resistance and lower transpiration in plants.

Electrolyte leakage enables cell membrane injury to be assessed when plants are subject to salinity stress. Maintaining integrity of cellular membranes under salt stress is considered an integral part of salinity tolerance mechanism (Stevens et al., 2006). Electrolyte leakage was greatly increased by salt stress in the study. It has been reported that salt stress led to a significant increase in the level of electrolyte leakage in many crop (Parida and Das, 2005). However, SA treatments lowered the electrolyte leakage in salt stressed

cucumber plants in this study. Earlier studies have indicated that exogenous SA applications could ameliorate the membrane deterioration in plants exposed to the salt stress; indicating SA facilitated the maintenance membrane functions (El-Tayeb, 2005; Stevens et al., 2006; Gunes et al., 2006). These results agree also with those of Shi et al. (2006) who reported that a foliar spray of 1.00 mM SA reduced electrolyte leakage and protected the cucumber plants against heat stress. Seneratna et al. (2000) and El-Tayeb (2005) suggested the decrease in membrane damages in salinity, drought or chilling stressed plants in response to exogenous SA could be related to the induction of antioxidant responses that protect the plant from oxidative damage. Szepsi et al. (2005) found that pre-treatment of tomato plants with SA enhanced antioxidant enzyme activities under salt stress, thus increasing the stress tolerance of plants. Wang and Li (2006) suggested that increased Ca in the cytoplasm might help maintain plasma membrane integrity to improve stress tolerance. Calcium plays an essential role in processes, which preserve the structural and functional integrity of plant membranes, stabilise cell wall structures, regulate ion transport and selectivity, and control ion-exchange behaviour as well as cell wall enzyme activities. Because calcium appears to be readily displaced from its membrane binding sites by other cations, these functions may become seriously impaired by reduced calcium availability (Grattan and Grieve, 1999). Our study showed SA raised Ca content in both shoot and root of cucumber compared to the control under salt stress. Exogenous SA has been shown to increase polyamine contents such as putrescine, spermidine, spermine in maize which preserve membrane integrity under stress conditions (Nameth et al., 2002). The SA application had no significant effect on electrolyte leakage in unstressed conditions.

The results of this study showed that salinity caused an increase in Na concentration and a decrease in N, P, K, Ca, Mg and the other minerals in both shoot and roots of cucumber plants regardless of SA treatments (Tables 1 and 2). Martinez and Cerda (1989) in cucumber, Feigin et al. (1987) in melon and tomato and Feigin et al. (1991) in lettuce and chinese cabbage reported that Cl from NaCl reduced NO_3 uptake by plans, thus decreasing N content in plant tissue. In earlier studies, salinity has been shown to decrease the concentration of P in plant tissue (Grattan and Grieve, 1999; El-Tayeb, 2005). Salinity dominated by Na and Cl not only reduces Ca and K availability, but reduces Ca and K transport and mobility to growing regions of the plant that affects the quality of both vegetative and reproductive organs. Furthermore, it has been reported that salt stress reduced the Mg, Mn, Fe, Zn, and Cu content in many horticultural crops (Grattan and Grieve, 1999; Gadallah, 1999). Many studies have shown that high concentrations of Na and Cl in the soil solution may depress nutrient-ion activities and produced extreme ratios of Na/Ca and Na/K in the plants, causing the plants to be susceptible to osmotic and specific-ion injury as well as to nutritional disorders that result in reduced growth, yield and quality (Grattan and Grieve, 1999; Essa, 2002; Sivritepe et al., 2003). In addition, numerous studies have demonstrated that NaCl salinity increased Na

content in plant tissue of vegetable crops (Sivritepe et al., 2003; De Pascale et al., 2003; Essa, 2002; Parida and Das, 2005). However, foliar SA treatments reduced the Na uptake of plants and/or increased the uptake of N, P, K, Ca, Mg, and the other studied minerals compared to control treatment under salt stress (Tables 1 and 2). Reducing Na content from SA treatments may result in low membranes injury, high water content and dry matter production. These observations are consistent with those of El-Tayeb (2005) who found that exogenously applied SA decreased Na and raised K, Ca, and P content in the shoots and roots of barley seedlings compared to those of non-treated ones under salt stress. Similarly, Gunes et al. (2005) and Gunes et al. (2006) determined that SA supply inhibited Na accumulation, but stimulated N, P, K, Mg, Fe, Mn, and Cu uptake by salt stressed maize plants compared to non-treated ones. They explained the positive effect of SA on growth of salt stressed maize plants could be attributed to decreasing levels of Na and Cl concentrations and increasing antioxidant activity. It was reported that SA decreased the Na/K ratio in the roots of salt stressed tomato plants (Szepsi et al., 2005). Wang and Li (2006) found out that pre-treatment with SA raised the cytoplasmic Ca in grape plants under heat and cold stress, inducing adaptation of plants to environmental stress.

Studies indicate that an increase in concentration of K and Ca in plants under salt stress could ameliorate the deleterious effects of salinity on growth and yield of vegetable crops (Grattan and Grieve, 1999; Sivritepe et al., 2003). Similarly, Satti and Lopez (1994) in tomato and Kaya et al. (2003) on pepper and cucumber determined that an increase in the concentration of K in the plants exposed to salt stress could ameliorate the deleterious effect of salt stress on the growth and yield. Alteration of mineral uptake from SA applications may be one mechanism for the alleviation of salt stress.

Biochemical strategies to cope with salt stress in plants include control of ion uptake and transport into leaves, compartmentalization of ions at cellular and whole-plant levels, synthesis of compatible solutes, alteration in membrane structure, change in photosynthetic pathway, induction of antioxidative enzymes and induction of plant hormones (Shim et al., 2003; Parida and Das, 2005). Plants with high levels of antioxidants, either constitutive or induced, have been reported to have greater resistance to this oxidative damage (Parida and Das, 2005). Salt stress leads to the formation of reactive oxygen species (ROS) such as superoxide, hydrogen peroxide. Reactive oxygen species can seriously disrupt normal metabolism through oxidative damage lipids, protein and nucleic acids. It is well known a number of antioxidants protect against the potentially cytotoxic species of activated oxygen (Parida and Das, 2005). Prevention of oxidative damage to cells during stress has been suggested as one of the mechanisms of stress tolerance. The improvement of stress tolerance is often related to enhancement of activities of antioxidant system in plants (Wang and Li., 2006). There are suggestions that SA acts as an antioxidant (Senaratna et al., 2000; Shim et al., 2003; Agarwal et al., 2005). Enhanced

activity of certain antioxidant enzymes with SA applications under stress conditions including salinity has been observed (Raskin, 1992; Borsani et al., 2001; He et al., 2002; Popova et al., 2003; Szalai et al., 2005; Shi et al., 2006; Gunes et al., 2006; Stevens et al., 2006).

Salt stress results in increased levels of 1-aminocyclopropane-1-carboxylate (ACC), a precursor to plant ethylene levels, inhibiting of root growth by stress-induced ethylene (Parida and Das, 2005). It has been reported that exogenous SA applications could control ACC levels or block ethylene biosynthesis in plants (Leslie and Romani, 1988; Ramanujam et al., 1998; Pandey et al., 2000).

It was observed that SA application might activate the metabolic consumption of soluble sugars to form new cell constitutes as a mechanism to stimulate growth and led to the increased proline accumulation (osmoprotectant) to reduce the injurious effects of salinity on the salt stressed tomato, barley and wheat plants (Szepsi et al., 2005; El-Tayeb, 2005; Shakirova et al., 2003). Furthermore, Sakhabutdinova et al. (2003) determined that presowing treatment with SA completely prevented salinity-induced declines in the concentration of indoleacetic acid and cytokinins in wheat seedlings.

CONCLUSION

The data obtained from the present study suggest that foliar SA applications can ameliorative the deleterious effects of salt stress by increasing chlorophyll content, photosynthetic activity, relative water content, uptake of mineral nutrients, antioxidant enzyme activity, controlling hormonal balance or decreasing Na uptake, membrane injurious, oxidative stress effect of NaCl, thus inducing salt tolerance in cucumber plants. These functions can have a key role in tolerance of cucumber plants to salt stress. It can be interpreted from the study although foliar SA treatments did not completely recover the deleterious effects of salt stress on the growth of cucumber seedlings, especially 1.00 mM SA treatment improved plant tolerance to salinity compared to the non-treated plants. Based on these findings, the SA treatments may help alleviate the negative effect of salinity on the growth of cucumber. Since salt stress effect on plant growth can change depending on stage of plant development tolerance. Therefore, assessments on effect of SA should be done throughout the other developmental stages of plant such as reproductive growth stage.

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