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Effects of salinity and relative humidity on two melon cultivars differing in salt tolerance

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Abstract

The effects of increasing relative humidity on the growth and salt tolerance of two melon (*Cucumis melo* L.) cultivars, Revigal C-8 (salt sensitive) and Galia (salt tolerant) was investigated. One month after germination, the plants were exposed for 15 d to 0 (control) and 80 mM NaCl, under relative humidity (RH), 30 and 70 %. The growth of the whole plant, leaf, stem and root of cv. Revigal C-8 was increased with increasing RH. On the other hand, cv. Galia showed an increase in root growth with increasing RH only under the NaCl treatment. Under salinity, most of the Na^+ was withheld in the stems. An increase in RH in the NaCl treatment significantly decreased Na^+ and Cl^- concentrations in leaves of cv. Revigal C-8, while it had no effect on their concentrations in cv. Galia. In both cultivars, increasing RH under NaCl condition significantly decreased water contents in leaves and stems, and increased osmotic potential in roots. The amount of the root exudate of cv. Galia was significantly decreased with increasing RH, while it was not affected in cv. Revigal C-8. Under the NaCl treatment, cv. Galia had significantly higher leaf osmotic potential than cv. Revigal C-8 at both relative humidities and higher amount of root exudate at 30 % RH.

Additional key words: *Cucumis melo* L., Na^+, osmotic adjustment, root hydraulic conductivity, stem.

Introduction

Muskmelon (*Cucumis melo* L.) is an important crop in arid and semiarid regions where many areas have indigenous salinity problems (Navarro *et al.* 1999). Muskmelon has been described as moderately salt-tolerant (Shmueli and Goldberg 1971, Shannon and Francois 1978, Meiri *et al.* 1981). However, cultivar variations in salt tolerance from sensitive to moderately tolerant have also been reported (Shannon *et al.* 1984, Mangal *et al.* 1988, Mendlinger and Pasternak 1992, Botia *et al.* 1998).

Salt tolerance of melon is affected by several factors such as root temperature (Borochov-Neori and Shani 1995), rootstocks (Romero *et al.* 1997), growth media (Kuehny and Morales 1998, Navarro *et al.* 1999), and carbon dioxide concentration (Mavrogianopoulos *et al.* 1999). Increasing air relative humidity (RH) may affect the salt tolerance of plants (Hoffman and Jobes 1978) by decreasing transpiration. The improvement in growth under high RH may be due to improvement in water relations of plants and/or reduction in salt accumulation in plant shoot (Salim 1989, An *et al.* 2001). It has been reported that growth reduction in saline conditions was ameliorated by increasing RH in bean plants, barley, maize, mangroves, *Albizia lebbek*, and tomato (Hoffman and Rawlins 1970, Hoffman and Jobes 1978, Ball *et al.* 1997, Kirdmanee *et al.* 1998, Paiva *et al.* 1998). However, other reports showed that humidity had no alleviation effect on the growth of cotton and wheat under saline conditions (Hoffman *et al.* 1971, Hoffman and Jobes 1978). Increasing RH decreased Na^+ and/or Cl^- uptake in many greenhouse plants (Gislerod *et al.* 1987, Gislerod and Mortensen 1990). On the contrary, salt tolerance was increased under conditions favouring higher transpiration in *Phragmites australis* (Lissner *et al.* 1999a,b). However, Ball (1988) reported that the effects of humidity on growth were not dependent on transpiration-linked transport of salt to the shoot.

Permeability of root to water and ions is a significant factor relating to salt tolerance. Salt tolerance depends on the capability of roots to restrict Na^+ and Cl^- transport

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to the shoot or the control of Na^+ concentration in the xylem sap (Durand and Lacan 1994). Läuchli (1984) reported that sodium exclusion by roots is a determinant of plant responses to salinity. Ion exclusion and accumulation are prominent features of salt-tolerant plants (Shannon *et al.* 1994).

Melon plants are sensitive to Na^+ and Cl^- specific toxicity (Carvajal *et al.* 1998, Navarro *et al.* 2000). Salt tolerance mechanisms in melon have been reported to be associated with Na^+ and/or Cl^- compartmentation (Botia *et al.* 1998), osmotic adjustment (Carvajal *et al.* 1998), exclusion of Cl^- and/or decrease in Cl^- absorption by roots (Romero *et al.* 1997).

In previous study (An *et al.* 2001), we found that in soybean increasing RH increased growth of the salt sensitive cultivar, but had no effect on the tolerant one. So far, no work has been done on the effects of RH on the salt tolerance of melon. The present study was, therefore, conducted with the objective of investigating the effects of RH on growth of two melon cultivars under saline and non-saline conditions.

Materials and methods

The experiment was carried out in two environmentally controlled growth chambers of the type *GC-A* (*Fuji Electric Co.*, Tokyo, Japan). Seeds of two melon (*Cucumis melo* L.) cultivars, Revigal C-8 and Galia, were germinated on filter paper. One week after germination, the young seedlings were transplanted into Hoagland and Arnon solution (Asagawa 1985). The solution strength was 1/3 and 2/3 during the 1^{st} and 2^{nd} week after transplanting, respectively, and full strength was used for the rest of the experimental period. Culture solution was replaced every 4 d. The pH of the solution was checked daily and maintained at 5.5 by adding HCl or KOH.

Thirty days after germination, uniform plants were selected from each cultivar and transferred to growth chambers. Each plant had about 6 leaves with a leaf area of about 520 cm^2 and a dry matter of about 1 g for the whole plant. The photoperiod was 12 h and the photon flux density, measured by a portable photosynthesis system (*LC-6400, LI-COR*, Lincoln, USA) at the canopy surface was 700 $\mu mol\ m^{-2}\ s^{-1}$. The day/night temperatures were 30 ± 0.1/20 ± 0.1 °C. One growth chamber was set at 30 and the other at 70 % RH, and the actual relative humidities recorded continuously were 30 ± 2 and 70 ± 5 %, respectively. The salinity treatment was applied by adding NaCl to the nutrient solution to reach a concentration of 80 mM. A nutrient solution without NaCl served as a control treatment. The plants of both cultivars were randomly arranged in the control and NaCl treatments at both relative humidities. Four replications for each treatment were assigned randomly. The humidity and salinity treatments lasted 15 d.

Nine days after the plants were exposed to NaCl and RH treatments, the fourth fully developed leaf of each plant was sampled. The roots, after being rinsed three times with distilled water, and leaves were wrapped in aluminum foil, immediately frozen in liquid nitrogen and stored at -20 °C (Rekika *et al.* 1998). The osmotic potential of the sap of these samples was measured by a freezing point osmometer (*OM 801, Vogel, Mediziniche Technik und Elektronik,* Berlin, Germany).

After 15 d of exposure to NaCl and RH treatments, shoots were cut 1 cm above the base of the stem. Plastic sleeves were sealed on the cut stems to collect the exudate. Three hours later, the exudate in the plastic sleeves was extracted by a syringe and the amount was determined. The plants were divided into leaf blades, stems plus petioles and roots. Leaf area was measured with an area meter (*AAL-410, Hayashi Denko Co.*, Tokyo, Japan). After fresh mass determination, the samples were dried at 80 °C for 3 d.

The amounts of Na^+ and Cl^- in leaf, stem and roots were measured with an ion chromatography (*Hitachi, D-7000,* Tokyo, Japan) as described by Chaudhary *et al.* (1996). The amounts of Na^+ and Cl^- in the root exudate were measured directly after dilution.

Means and standard errors (± SE) are presented. Significance of differences between treatments was estimated using the Student's *t*-test (Yonezawa *et al.* 1988).

Results

The NaCl treatment decreased the growth of cv. Revigal C-8 by 52 and 53 % at 30 and 70 % RH, respectively, whereas the decrease in the growth of cv. Galia was 27 and 10 %, respectively (Fig. 1). The growth of leaves, stems and roots of cv. Revigal C-8 was significantly increased with increasing RH under both control and NaCl treatments, but in cv. Galia the only significant increase was observed in the growth of root under the NaCl treatment. Fresh mass of the whole plant, leaf, stem and root (Fig. 1) showed a similar trend as that of dry mass in response to NaCl and RH.

Leaf area was significantly decreased by NaCl in both cultivars at both relative humidities (Fig. 1). Increasing RH significantly increased the leaf area of cv. Revigal C-8

in the control treatment, but the increase was only slight under the NaCl treatment. Cultivar Galia, on the other hand, showed a slight decrease in leaf area at both control and NaCl treatments with increasing RH.

The stem length of both cultivars was significantly decreased by NaCl under both relative humidities (Fig. 1). Increasing RH significantly increased the stem length in cv. Revigal C-8 only under the NaCl treatment. The stem length of cultivar Galia was not significantly affected by RH under both control and NaCl treatments.

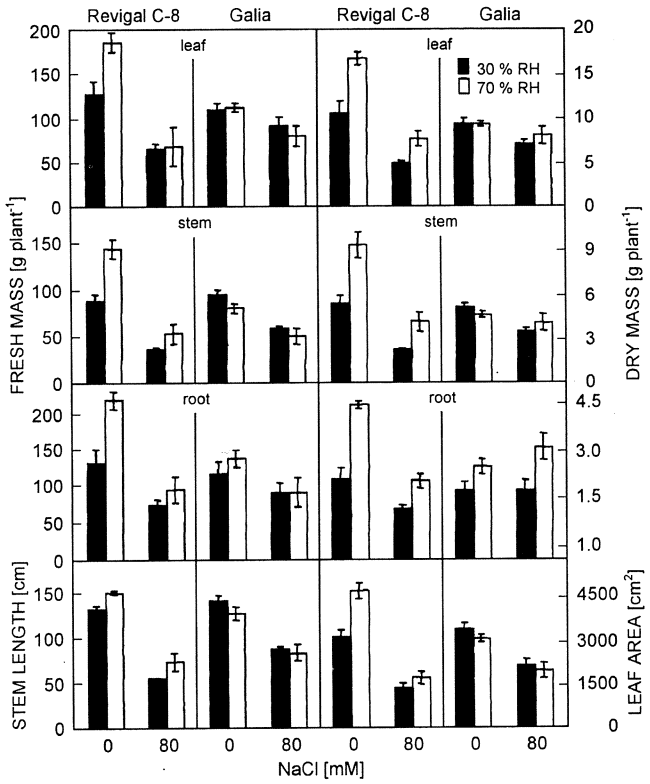

Fig. 1. Fresh mass, dry mass, stem length and leaf area of the two melon cultivars, Revigal C-8 and Galia, after 15-d exposure to 0 or 80 mM NaCl at 30 or 70 % relative humidity (RH). Means ± SE, $n = 4$.

Table 1. Water content [%] of two melon cultivars, Revigal C-8 and Galia, after 15-d exposure to 0 or 80 mM NaCl at 30 or 70 % relative humidity. Means ± SE, $n = 4$. Those not significantly different from each other in the same tissue of both cultivars are followed by the same letter ($P = 0.05$).

Cultivar		0 mM NaCl		80 mM NaCl	
		30 %	70 %	30 %	70 %
Revigal C-8	leaf	91.29 ± 0.19^{ab}	90.58 ± 0.35^{ab}	92.07 ± 0.20^{a}	84.29 ± 1.29^{c}
	stem	93.74 ± 0.41^{b}	93.51 ± 0.18^{b}	93.64 ± 0.19^{b}	91.67 ± 0.40^{c}
	roots	98.07 ± 0.07^{a}	97.77 ± 0.08^{ab}	97.81 ± 0.13^{ab}	97.22 ± 0.32^{b}
Galia	leaf	91.62 ± 0.08^{a}	91.65 ± 0.23^{a}	92.26 ± 0.35^{a}	89.67 ± 0.75^{b}
	stem	94.92 ± 0.04^{a}	94.34 ± 0.39^{a}	94.22 ± 0.10^{a}	91.95 ± 0.29^{c}
	roots	98.16 ± 0.08^{a}	97.92 ± 0.09^{a}	97.64 ± 0.09^{ab}	93.57 ± 0.48^{c}

In both cultivars, NaCl application significantly increased Na^+ and Cl^- concentrations in all plant tissues at both relative humidities (Fig. 2). The highest concentration of Na^+ was found in the stems of both cultivars under both levels of salinity and RH. With NaCl application, there was a gradual increase in Cl^- concentration from the lower to the upper part of the plant in both cultivars except in cv. Revigal C-8 at 70 % RH where there was a slightly higher Cl^- concentration in the stem than in leaf.

Under the NaCl condition, increasing RH significantly decreased Na^+ concentration in leaves of cv. Revigal C-8, but had no significant effect on its concentration in the stems and roots (Fig. 2). In cv. Galia,

however, the increase in RH had no significant effect on Na^+ concentration in leaves, stems and roots. In the case of Cl^- accumulation under the NaCl treatment, increasing RH significantly decreased Cl^- concentration in leaves of cv. Revigal C-8, whereas in cv. Galia the only significant decrease was found in the stems.

NaCl application significantly increased Na^+ and Cl^- concentrations in the root exudate of the two cultivars at both relative humidities (Fig. 2). At both relative humidities, cv. Galia had significantly lower Na^+ concentration than cv. Revigal C-8. Increasing RH significantly decreased Na^+ and Cl^- concentrations in the root exudate of both cultivars under NaCl treatment.

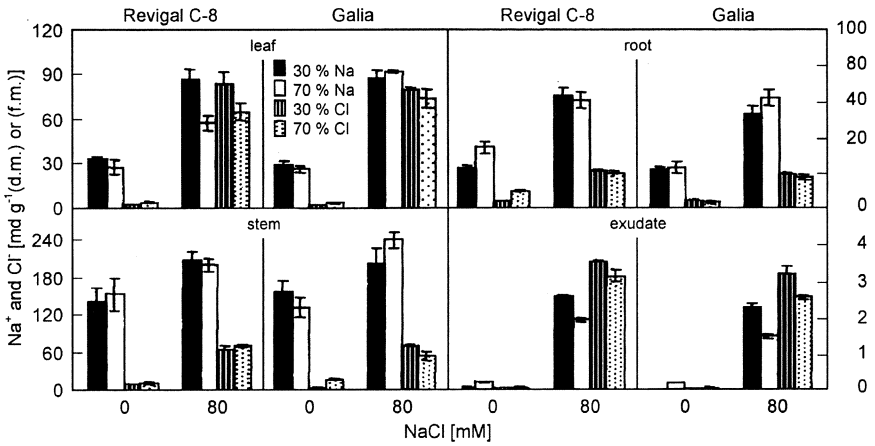

Fig. 2. Na^+ and Cl^- concentrations in leaf, stem, root and exudate of the two melon cultivars, Revigal C-8 and Galia, after 15-d exposure to 0 or 80 mM NaCl at 30 or 70 % relative humidity (RH). Means ± SE, $n = 4$.

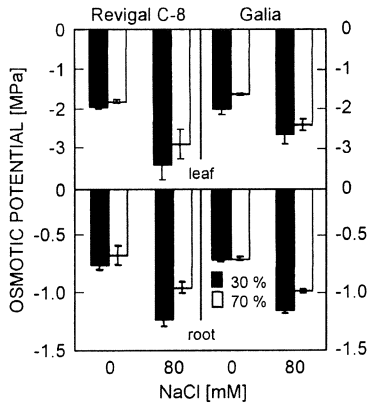

Fig. 3. Leaf and root osmotic potentials of the two melon cultivars, Revigal C-8 and Galia, after 15-d exposure to 0 or 80 mM NaCl at 30 or 70 % relative humidity (RH). Means ± SE, $n = 4$.

Osmotic potentials of the leaves and roots of both cultivars were significantly decreased under the NaCl treatment compared with the control (Fig. 3). Cultivar Revigal C-8 had significantly lower osmotic potential in the leaves than cv. Galia at both relative humidities. Under the NaCl treatment, increasing RH significantly increased the osmotic potential of roots and decreased the water contents in leaves and stems of both cultivars (Fig. 3 and Table 1).

Table 2. Amount of exudate [mg g^{-1} (root f.m.)] from the roots of two melon cultivars, Revigal C-8 and Galia, after 15-d exposure to 0 or 80 mM NaCl at 30 or 70 % relative humidity (RH). Means ± SE, $n = 4$. Those not significantly different from each other in the same column are followed by the same letter ($P = 0.05$).

Cultivar	RH [%]	0 mM NaCl	80 mM NaCl
Revigal C-8	30	80.58 ± 3.71^b	2.68 ± 0.31^b
	70	97.70 ± 1.15^a	1.87 ± 0.15^b
Galia	30	70.30 ± 5.02^b	4.78 ± 0.38^a
	70	64.89 ± 1.35^b	2.17 ± 0.07^b

NaCl application decreased the amount of root exudate in both cultivars at both relative humidities (Table 2). Cultivar Galia had significantly higher amount of root exudate than cv. Revigal C-8 at 30 % RH under NaCl treatment. Increasing RH significantly increased the amount of root exudate in cv. Revigal C-8 under the control treatment, but did not affect that of cv. Galia. However, under the NaCl treatment, cv. Galia had significantly higher amount of root exudate at 30 % RH than at 70 % RH, while in cv. Revigal C-8 there was no significant difference in the amount of root exudate between the two relative humidities.

Discussion

The lower decrease in the growth of cv. Galia observed under the NaCl treatment at both relative humidities compared with that of cv. Revigal C-8 (Fig. 1) indicates that cv. Galia is more tolerant to NaCl than cv. Revigal C-8 (Maas 1986). The increased growth of cv. Revigal C-8 with increasing RH under both control and NaCl treatments, and the unchanged growth of cv. Galia with increasing RH under both conditions shows that higher RH has a positive effect only on the growth of the salt sensitive cultivar. However, the unchanged growth of cv. Galia with increasing RH under both control and NaCl treatments may also indicate its tolerance to air drought. These results are in agreement with those reported for soybean cultivars differing in salt tolerance (An *et al.* 2001). Botia (1998) reported that the NaCl concentration at which growth is reduced by 50 % for cv. Galia at early vegetative growth is about 50 mM. Therefore, the results obtained in this study indicate that salt tolerance of melon plants increased with growth (Franco *et al.* 1993).

The similar trends of leaf area expansion and total plant growth of cv. Revigal C-8 in response to NaCl at both relative humidities and those of cv. Galia at 30 % RH demonstrated the interaction between leaf area expansion and plant growth under NaCl condition. Under NaCl condition, although leaf area of both cultivars was not significantly affected by RH, the total plant growth of the cv. Revigal C-8 (Fig. 1) was significantly increased. This suggests that other factors are involved in the growth response of plants to RH elevation under NaCl condition. Furthermore, the significantly decreased leaf area and the similar growth of cv. Galia at 70 % RH under NaCl treatment may also lead to the same conclusion.

The markedly depressed stem growth of cv. Revigal C-8 under NaCl condition (Fig. 1) might be associated with its sensitivity to NaCl, since stem is a very important organ to reabsorb Na^+ from xylem stream by the surrounding tissues and thus reduces the amount of Na^+ reaching leaves (Durand and Lacan 1994). On the contrary, the less depressed stem growth in cv. Galia under NaCl condition might contribute to its salt tolerance.

Although there was no significant difference in dry mass accumulation between the control and NaCl treatments in cv. Galia at 70 % RH (Fig. 1), the appearance of the plant in terms of leaf area and stem length (Fig. 1) was significantly affected by NaCl application. Therefore, dry mass accumulation should not be considered as the only criterion for evaluating salt tolerance in plants.

Under the NaCl treatment, the highest Na^+ concentration in the stem compared with that in the leaf and roots (Fig. 2) demonstrate the importance of the stem to the salt tolerance of plants. This result is consistent with that obtained for stem and whole plant growth of the two cultivars under saline condition (Fig. 1). However, the significantly higher concentration of Na^+ in the leaves of both cultivars at both relative humidities under saline condition compared with those under the control treatment (Fig. 2) indicate that the capacity of withholding Na^+ in the stem is limited and thus some Na^+ are released to the leaves and/or the plants may transport Na^+ to leaves for osmotic adjustment (Leidi and Saiz 1997).

The similar or higher Na^+ or Cl^- concentrations in the leaves of the salt tolerant cv. Galia at 30 or 70 % RH compared with the salt sensitive cv. Revigal C-8 (Fig. 2) indicate that Na^+ and Cl^- accumulations in leaves do not determine the differences in salt tolerance among melon cultivars. Furthermore, it implies that Na^+ and Cl^- accumulation in melon leaves may be associated with compartmentation (Botia *et al.* 1998). However, the significantly decreased Na^+ and Cl^- concentrations in the leaves of cv. Revigal C-8 at 70 % RH compared with those at 30 % RH might contribute to its better growth under high RH in terms of reducing the toxic effects of Na^+ or Cl^- (Dudley 1992) and consequently reducing the amount of energy needed for osmotic adjustment (Carvajal 1998). On the contrary, the similar Na^+ or Cl^- accumulation in the leaves of cv. Galia at 30 and 70 % RH might explain its unchanged growth under the two relative humidities (Fig. 1), as there is a significant correlation between its growth and Na^+ concentration in plant tissue (Navarro *et al.* 2000).

Under the NaCl treatment, the pattern of Cl^- distribution in plant tissues of the two cultivars at both relative humidities (Fig. 2) suggests that the plants may accumulate Cl^- in leaves for osmotic adjustment (Munns and Termaat 1986) or for electrically balancing cations (Adam 1990). The higher concentration of Cl^- compared with Na^+ in the exudate and the lower Cl^- accumulation in plant tissues compared with Na^+ (Fig. 2) might suggest that there may be a top down control of Cl^- uptake and transport in transpiring melon plants.

The significantly higher osmotic potentials in the leaves of cv. Galia compared with those of cv. Revigal C-8 under NaCl treatment at both relative humidities indicate that less energy was consumed for osmotic adjustment in cv. Galia compared with cv. Revigal C-8 (Carvajal *et al.* 1998). This may explain the differences in growth between these cultivars under NaCl treatment (Fig. 1, An *et al.* 2002). As the leaf turgor pressure in melon plants does not change under saline conditions (Carvajal *et al.* 1998), the leaf water potential of cv. Galia might be higher than that of cv. Revigal C-8. The decrease in energy consumption and improved water status may be the main factors related to the salt tolerance characteristics of cv. Galia. The significantly decreased Na^+ and Cl^- concentrations in the leaves of cv. Revigal C-8 with increasing RH (Fig. 2) and the comparable leaf osmotic potentials at the two relative humidities (Fig. 3)

may imply that cv. Revigal C-8 achieved the osmotic adjustment in the leaves partly by decreasing the water content in leaves (Table 1). This way of osmotic adjustment may be with the lowest cost. The same strategy can be observed in cv. Galia (Fig. 3 and Table 1).

The comparable leaf osmotic potentials at the two relative humidities for each cultivar (Fig. 3) indicate that the osmotic adjustment in the leaves is not affected by RH and may be dependent on the root environment. However, under the NaCl treatment, higher RH may increase osmotic potential gradient from root to leaf because increasing RH increased osmotic potential in the root (Fig. 3). On the other hand, the osmotic potential gradient between saline culture medium and root could be high at low RH and low at high RH, respectively. The lower osmotic potential gradient between saline culture medium and root at high RH may increase the requirement of the plant for active ion absorption by roots as indicated by an increase in root growth of both cultivars (Fig. 1). Roots may absorb ions selectively resulting in a reduction in Na^+ uptake (Fig. 2).

Compared with the control, the significant decrease in the amount of exudate from roots of plants exposed to NaCl (Table 2) might be due to a decrease in hydraulic conductance caused by a decrease in water channel activity in the roots (Carvajal *et al.* 2000). The higher amount of exudate from roots of cv. Galia compared with cv. Revigal C-8 may imply that cv. Galia has higher hydraulic conductivity in the root than cv. Revigal C-8 (Martinez-Ballesta *et al.* 2000). Under the NaCl treatment, the lower amounts of exudate from roots of both cultivars grown at high RH compared with those at low RH indicate that root activity decreases under high RH (Katou 1998).

The significantly lower Na^+ concentrations in the root exudate of cv. Galia compared with those in cv. Revigal C-8 at both relative humidities (Fig. 2) might indicate that the roots of cv. Galia have lower permeability to Na^+ than those of cv. Revigal C-8. The effects of this root characteristic on Na^+ accumulation in transpiring plants need to be verified as the final accumulation of Na^+ in cv. Galia was not significantly lower than that in cv. Revigal C-8 (Fig. 2). This result confirms earlier findings that no exclusion mechanism for salt tolerance exists in this crop (Greenway and Munns 1980, Botia *et al.* 1998). It also suggests that the concentrations of ions in the exudate of detoped plants may not represent their actual concentrations in transpiring plants.

It may be concluded that cv. Revigal C-8 is sensitive to NaCl and low air humidity, while cv. Galia is tolerant to NaCl and low air humidity. Increasing RH showed a positive effect on the growth of the salt and low humidity sensitive cultivar, but had no effect on the tolerant one. The differences in ionic relations of the two cultivars in response to NaCl and RH are associated with the differences in their growth. Salt tolerance in cv. Galia is associated with higher osmotic potential, better water relations in leaves and higher hydraulic conductivity in roots. Increasing RH decreased Na^+ and Cl^- accumulations in leaves of cv. Revigal C-8, which may be the main reason that led to its increased growth. However, increasing RH did not affect Na^+ and Cl^- accumulations in leaves of cv. Galia and even decreased the hydraulic conductivity in roots. These may explain why there is no increase in the growth of this cultivar with increasing RH. These findings also suggest that cv. Galia has some degree of tolerance to air drought.

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