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Effect of Salinity on Yield, Fruit Quality, Leaf Gas Exchange, and Mineral Composition of Grafted Watermelon Plants

Guiseppe Colla,[1] Youssef Roupahel, and Mariateresa Cardarelli
Dipartimento di Produzione Vegetale, Università della Tuscia, via S.C. De Lellis snc, 01100 Viterbo, Italy

Elvira Rea
Consiglio per la Ricerca e la Sperimentazione in Agricoltura–Istituto Sperimentale per la Nutrizione delle Piante, 00159 Rome, Italy

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Abstract. **A greenhouse experiment was carried out to determine growth, yield, fruit quality, gas exchange and mineral composition of watermelon plants (*Citrullus Lanatus* L. 'Tex'), either ungrafted or grafted onto two commercial rootstocks 'Macis' [*Lagenaria siceraria* (Mol.) Standl.] and 'Ercole' (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) and cultured in NFT. Plants were supplied with a nutrient solution having an electrical conductivity (EC) of 2.0 or 5.2 dS·m^{-1}. The saline nutrient solution had the same basic composition, plus an additional of 29 mM of NaCl. Increased salinity in the nutrient solution decreased total yield. The reduction in total yield in saline treatments compared to control was due to a reduction in the fruit mean mass and not to the number of fruit per plant. Total fruit yield was 81% higher in grafted than in ungrafted plants. The lowest marketable yield recorded on ungrafted plants was associated with a reduction in both fruit mean mass and the number of fruits per plant in comparison to grafted plants. Salinity improved fruit quality in all grafting combinations by increasing dry matter (DM), glucose, fructose, sucrose, and total soluble solid (TSS) content. Nutritional qualities of grafted watermelons such as fruit DM, glucose, fructose, sucrose, and TSS content were similar in comparison to those of ungrafted plant. In all grafting combinations, negative correlations were recorded between Na^+ and Cl^- in the leaf tissue and net assimilation of CO_2. Grafting reduced concentrations of sodium, but not chloride, in leaves. However, the sensitivity to salinity was similar between grafted and ungrafted plants and the higher total yield from grafting plants was mainly due to grafting per se.**

Salinity stress is the major environmental factor limiting plant growth and productivity in arid and semiarid regions (Parida and Das, 2005). Most of the crops cannot survive under conditions of high salinity or can survive only with decreased yields. There are three main physiological mechanisms inducing stress under salinity conditions: 1) lower water potential of the root medium, 2) toxic effects of Na^+ and Cl^-, and 3) nutrient imbalance by depression in uptake and/or shoot transport (Lauchli, 1986; Marschner, 1995; Munns and Termaat, 1986). Overcoming salt stress problems would have a positive impact on agriculture production. Numerous attempts have been made to improve the salt tolerance of crops by traditional breeding programs and by genetic transformation of plants. However, commercial success has been very limited due to the complexity of the trait: salt tolerance is complex genetically and physiologically (Flowers and Flowers, 2005). Growers demand a higher yielding and/or higher quality varieties, despite the plants being generally salt sensitive. Thus, the search for strategies directed understanding the deleterious effects of salt stress in the plants continues to be an objective of great interest. One way of avoiding or reducing losses in production caused by salinity in high-yielding genotypes would be to graft them onto rootstocks capable of reducing the effect of external salt on the shoot. This strategy could also provide the plant breeder with the possibility of combining good shoot characters with good root characters, and of studying the contribution of genes transcribed in the roots towards the performance of the shoot (Pardo et al., 1998; Zijlstra et al., 1994).

Grafting was used widely with watermelon to limit the effects of fusarium wilt (Lopez-Galarza et al., 2004; Miguel et al., 2004) and to improve the mineral nutrition of watermelon plants (Pulgar et al., 2000), but the reasons for grafting, as well as the kinds of vegetables grafted, have increased dramatically over the years. For example, grafts have been used to induce resistance against low (Bulder et al., 1990) and high (Rivero et al., 2003a) temperatures; against iron chlorosis in calcareous soils (Romera et al., 1991); to enhance nutrient uptake (Ruiz et al., 1997) and to improve water use (Cohen and Naor, 2002). Many studies have been carried out to determine the response of grafted trees to saline conditions. However, grafting has rarely been used to increase productivity of vegetables under adverse conditions (Ruiz et al., 1997). Previous results on tomato (Fernandez-Garcia et al., 2002, 2003; Santa-Cruz et al., 2002; Estan et al., 2005) and melon (Romero et al., 1997) reported that the improvement of salt tolerance by grafting is related to the capability of rootstocks to exclude potentially toxic Na^+ and/or Cl^-; Romero et al., (1997) suggested that the grafted melon plants developed various mechanisms to avoid physiological damage caused by excessive accumulation of these ions in leaves, including the exclusion and/or reduction of absorption of Cl^- by the roots and the replacement or substitution of total K^+ by total Na^+ in the foliage. In the present study, we hypothesized that grafting on Cucurbita rootstocks (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) might raise the salt tolerance of watermelon through limiting the transport of sodium and/or chloride to the shoot as reported in literature on tomato and melon. To verify, this hypothesis, a greenhouse experiment was carried out to answer this question. Watermelon plants were grown in a recirculating nutrient solution system (NFT) using saline and nonsaline nutrient solutions. Grafted and ungrafted plants were compared in terms of yield, growth, fruit quality, gas exchange, mineral composition and assimilate partitioning.

Materials and Methods

Plant material and growth conditions. The experiment was conducted in Spring–Summer 2004 growing season in a 300 m^2 polyethylene greenhouse situated on the Experimental Farm of Tuscia University, Central Italy (lat. 42°25'N, long. 12°08'E). Plants were grown under natural light conditions. The greenhouse was maintained at daily temperatures between 18 and 33 ºC, and day/night relative humidities of 55/85%, respectively. *Citrullus lanatus* L. 'Tex' (Taki, Japan) was grafted onto the commercial rootstocks 'Macis' [*Lagenaria siceraria* (Mol.) Standl., Nunhems Zaden, The Netherlands] and 'Ercole' (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne, Nunhems Zaden, The Netherlands) using the procedure of cleft grafting described by Lee (1994), while ungrafted 'Tex' was used as a control. 'Tex' was selected as a representative mini-watermelon hybrid cultivated in Italy. At the two true-leaf stage (15 Apr. 2004) grafted and ungrafted plants were transplanted into rockwool cubes (7.5 × 7.5 × 6.5 cm) and then placed on 25 cm wide and 6-m-long NFT channels, with 60 cm between rockwool cubes and 120 cm between NFT channels, giving a plant density of 1.4 plants/m^2. Plants were trained vertically using a plastic net. Treatments were arranged in a randomized complete-block design with three replicate NFT channels per treatment. The treatments were defined by a factorial combination of two solution conductivities (2.0 or 5.2 dS·m^{-1}) and three grafting combinations (nongrafted Tex; Macis/Tex or Ercole/Tex). Each experimental unit consisted of one NFT channel containing ten plants.

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Nutrient solution management. The control nutrient solution had an electrical conductivity (EC) of 2.0 dS·m^{-1} which contained: 14.4 mM N-NO_3, 1.8 mM S, 1.2 mM P, 6.0 mM K, 4.0 mM Ca, 2.3 mM Mg, 1.0 mM Na, 1.0 mM Cl, 20 μM Fe, 9 μM Mn, 1.5 μM Cu, 3 μM Zn, 20 μM B, 0.3 μM Mo. The saline nutrient solution had the same composition plus 29 mM NaCl, resulting in an EC of 5.2 dS·m^{-1}. The solution of each tank (one tank of 100 L per experimental unit) was brought to its initial volume by daily addition of deionized water. Moreover the EC and pH were measured daily in all the nutrient solution treatments and if necessary they were adjusted to the initial values by adding concentrated nutrient solution and acid mixture with the same anionic ratio of nutrient solution (1N–0.08P–0.12S). Nevertheless, to accurately maintain the targeted NaCl concentration in the NaCl-enriched nutrient solution, the Na concentration in the recirculating nutrient solution was measured by inductively coupled plasma emission spectrophotometer (ICP Iris; Thermo Optek, Milano, Italy) and adjusted twice weekly. Moreover, the nutrient solutions were completely renewed from all tanks every 10 d. To prevent large fluctuations in EC, pH and ionic concentrations in the intervals between the replacements of the nutrient solutions, a relatively high volume of nutrient solution per plant (10 L) was recirculating in all treatments. Consequently, the variation of the EC values of the nutrient solution in all treatments was never greater than 5% of the initial value. In each NFT channel (experimental unit) an independent tank was provided to supply plants with nutrient solution. Each NFT channel had an independent tank to provide nutrient solution. The nutrient solution was pumped and delivered at 2 L·min^{-1} at the top end of every bench and allowed to run slowly down the trough and the excess was drained back to the tank for later recirculation.

Measurements and analysis. Fully mature fruits were harvested from 6 June to 7 July, and the number of fruits, mean fruit mass, and early (from 6 June to 21 June) and total yields were determined on five plants per plot. Three representative marketable fruits of each plot were analyzed for fruit quality parameters. Immediately after harvest, fruit shape index (SI), defined as the ratio of width to length was measured. The selected fruits were then cut into slices and separated into pulp, peel and seeds and all fractions were weighed. From the liquid extract obtained from liquefying and filtering the mesocarp of each fruit, total soluble solids (TSS) contents in juice was determined by an Atago N1 refractometer (Atago Co. Ltd., Japan) and expressed as ºBrix at 20 ºC. Acidity was determined by potentiometric titration with 0.1 M NaOH up to pH 8.1 using 15 mL of juice. Results were expressed as percentage malic acid in the juice. Fruit juice EC and pH were also measured with a conductivity meter (HI-991301; Hanna Instruments, Padova, Italy) and with a pH meter (HI-9023; Hanna Instruments, Padova, Italy).

Watermelon flesh samples of approximately 50 g were removed from the center of the slice, frozen at –80 °C, freeze-dried and stored in polyethylene bags at –20 °C for the analysis of glucose, fructose, sucrose. Analysis of glucose, fructose and sucrose were determined through an enzyme linked spectrophotometric assay as described by Jones et al. (1977), using the modification of Antognozzi et al. (1996).

Fruit were dried in a forced-air oven at 80 °C for 72 h and weighed to determine the fruit dry matter (DM). Dry fruit were ground in a Wiley mill to pass through a 20-mesh screen and 0.5 g of the dry fruit were analyzed for the following elements: K, Na, and Cl. Potassium and Na were determined by dry ashing at 400 °C for 24 h, dissolving the ash in HNO_3 1:20 v/v and assaying the solution obtained using an inductively coupled plasma emission spectrophotometer (ICP Iris; Thermo Optek, Milano, Italy) (Karla, 1998). Chloride ion concentration was determined by titration with $AgNO_3$ in the presence of K_2CrO_4 (Eaton et al., 1995).

Gas exchange measurements were done 50 d after transplanting (3 June). Measurements were made on the most recent fully expanded leaves, giving five replicates per treatment. Light-saturated (*PPF* = 1000 μmol·m^{-2}·s^{-1}) net assimilation of CO_2 (A_{CO_2}) and stomatal conductance (g_s) were determined with a portable photosynthesis system (LI-6200; LI-COR Inc., Lincoln, Neb.). The LI-6200 was equipped with a well-stirred 2.5 × 10^{-5} m^3 leaf chamber with constant-area inserts (1.2 × 10^{-3} m^2) and fitted with a variable intensity red source (model QB1205LI-670; Quantum Devices Inc. Barneveld, Wis.) (Tennessen et al., 1994). Leaf temperature within the chamber was 30 ± 2 °C and vapour pressure difference between the leaf and air was 2.6 ± 0.3 °C. The CO_2 concentration was 365 ± 10 μL·L^{-1}. All gas exchange measurements were made between 0900 and 1200 HR.

At final harvest (8 July, 85 d after transplanting), five plants per plot were separated into stems, leaves and roots. Leaf area (LA) was measured with an electronic area meter (Delta-T Devices Ltd, Cambridge, U.K.), and the plant samples were oven dried for biomass determination and subsequently ground for K, Na, and Cl determination as previously described. Harvest index (HI) was calculated as the ratio of dry matter partitioned into the fruit relative to the total plant biomass.

Statistical analysis. All data were statistically analyzed by ANOVA using the SPSS software package (SPSS 10 for Windows, 2001). Duncan's multiple range test was performed at $p = 0.05$ on each of the significant variables measured.

Results

Fruit yield components. Total fruit yield and mean fruit mass were significantly affected by salinity level and grafting combination, with no significant salinity × grafting interaction (Table 1). Moreover, the fruit number was highly influenced by grafting combination but not by salinity; there was no salinity × grafting interaction. Relative to plant grown in control solution, total fruit yields of nongrafted Tex, Tex/Macis and Tex/Ercole plants exposed to saline solution were reduced by 19.6%, 16.0%, and 16.2%, respectively. The decrease in total

Table 1. Effects of grafting combination and salinity level on total yield, mean fruit mass, and number of watermelons per plant.

Grafting combination	Salinity level (dS·m^{-1})	Total yield (kg/plant)	Total fruit	
			Number (n/plant)	Mean mass (kg/fruit)
Nongrafted Tex	2.0	6.1 c[z]	4.4 b	1.37 bc
	5.2	4.9 d	4.3 b	1.13 c
Tex/Macis	2.0	10.6 a	6.5 a	1.63 ab
	5.2	8.9 b	6.0 a	1.48 b
Tex/Ercole	2.0	11.1 a	5.9 a	1.89 a
	5.2	9.3 b	6.0 a	1.54 b
Significance				
Grafting combination (G)		***	**	**
Salinity (S)		***	NS	**
G × S		NS	NS	NS

[z]Means within columns separated using Duncan's multiple range test, $p = 0.05$.
NS,**,***Nonsignificant or significant at $p < 0.01$ or 0.001, respectively.

Table 2. Effects of grafting combination and salinity level on biomass production, partitioning and harvest index (HI) of watermelon plants.

Grafting combination	Salinity level (dS·m^{-1})	Dry mass (g/plant)					
		Leaves	Stems	Fruit	Roots	Total	HI
Nongrafted Tex	2.0	52.2 c[z]	25.7 c	592.6 c	4.4 b	674.9 c	0.88 b
	5.2	36.6 d	15.1 d	507.6 d	4.1 b	567.0 d	0.90 a
Tex/Macis	2.0	122.1 a	87.2 a	1061.7 a	13.5 a	1284.4 a	0.83 d
	5.2	90.0 b	48.5 b	961.3 b	13.2 a	1110.7 b	0.87 c
Tex/Ercole	2.0	128.3 a	91.1 a	1074.2 a	15.0 a	1308.5 a	0.82 d
	5.2	98.2 b	50.9 b	971.5 b	14.1 a	1134.7 b	0.86 c
Significance							
Grafting combination (G)		***	***	***	***	***	***
Salinity (S)		***	***	***	NS	***	**
G × S		NS	NS	NS	NS	NS	NS

[z]Means within columns separated using Duncan's multiple range test, $p = 0.05$.
NS,**,***Nonsignificant or significant at $p < 0.01$ or 0.001, respectively.

yield caused by an increase of the nutrient solution EC was attributed to a reduction in the fruit mean mass and not to a change in the number of fruit per plant (Table 1). The total fruit yield was higher by 81% in grafted than in nongrafted plants, with no significant difference observed between rootstocks (Tex/Macis and Tex/Ercole) (data not shown). The low total yield of ungrafted plants was due to both low mean fruit mass and low fruit number (Table 1).

Biomass production and partitioning. The dry mass of all plant parts were significantly affected by grafting combination, with no significant salinity × grafting interaction. Moreover, the dry mass of leaves, stems, fruits and total biomass were highly influenced by salinity (Table 2). The dry mass of leaves, stems and total biomass was higher in grafted plants in comparison to ungrafted plants, with no significant difference between rootstocks (Tex/Macis and Tex/Ercole). The fruit dry mass results were fully consistent with those reported for the fresh mass (Table 1). Harvest index (HI) was 3.9% higher at 5.2 $dS \cdot m^{-1}$ in comparison to the 2.0 $dS \cdot m^{-1}$ treatment, while the effect of the grafting combination was more pronounced with an increase by 5.3% in ungrafted treatments compared with grafted plants (Tex/Macis and Tex/Ercole) (Table 2). HI was 3.9% higher for plants in saline compared to control solution. This effect of salinity was more pronounced in ungrafted compared with grafted plants (Table 2).

Fruit quality. The relative amounts of peel, pulp and seeds were significantly affected by salinity level, but not grafting combination; there was a significant grafting combination × salinity interaction for peel and pulp percentages (Table 3). Grafted plants (Tex/Macis and Tex/Ercole) receiving a control nutrient solution exhibited the highest percentage of peel, while the highest percentage of pulp were recorded in both grafted combinations receiving a saline nutrient solution. Pulp values decreased whereas peel values increased in response to an increase of nutrient solution salinity for grafted plants, while no significant variations were recorded for ungrafted plants. Among treatments, the percentage of seeds decreased with increasing salinity, whereas no significant difference among treatments was observed for shape index (SI; avg. 0.98) (Table 3).

The fruit dry matter (DM), total soluble solids (TSS) contents and pH were significantly affected by salinity level but not by the grafting combination and the salinity × grafting interaction, whereas the fruit juice electrical conductivity (EC) was significantly affected by both salinity levels and grafting combinations, but interactions of these two factors were not observed (Table 4). When averaged over grafting combinations, increasing the nutrient solution salinity increased DM, TSS contents and EC by 12%, 9%, and 8%, respectively, and decreased pH by 4%. The EC of fruit juice from both grafted plants was significantly higher than that of ungrafted plants. No significant difference among treatments was observed for acidity concentration (avg. 0.076%). Glucose, fructose, sucrose and total sugars (expressed as g per 100 g of fresh mass) were significantly affected by the salinity level ($p < 0.01$) but not by the grafting combination and the salinity × grafting interaction (data not shown). Averaged over all plants, saline solution increased the contents of sugars in the fruit. This increase was from 1.80 to 2.19 g/100 g fresh weight for glucose; from 3.29 to 3.62 g/100 g fresh weight for fructose; from 1.16 to 1.49 g/100 g fresh weight for sucrose; and from 6.25 to 7.30 g/100 g fresh weight for total sugars.

Leaf gas exchange. The final leaf area (LA) was significantly affected by both salinity level and grafting combination, with no significant interaction between those factors (Table 5). When averaged over salinity levels, the LA was higher by 149% in grafted (0.79 m^2/plant) than in nongrafted plants (1.98 m^2/plant), with no significant difference observed between rootstocks (Tex/Macis and Tex/Ercole). When averaged over grafting combinations, the LA was higher by 38% for plants in control (1.84 m^2/plant) compared to saline solution (1.33 m^2/plant) (Table 5). Salinity decreased g_s by 39% when averaged over grafting combinations. Differences in A_{CO_2} were also observed between salinity treatments and between grafted and ungrafted plants. Ungrafted plants receiving the control nutrient solution exhibited the highest values of A_{CO_2} followed by the Tex/Macis and the Tex/Ercole treatments. A_{CO_2} decreased with increasing salinity in all grafting combinations, especially in ungrafted Tex treatment (Table 5). Finally, the data showed an inverse linear relationship between A_{CO_2} and leaf Na^+ and leaf Cl^- concentrations (Fig. 1).

Mineral composition and partitioning. A significant salinity × grafting interaction was observed for K concentration in leaves, with

Table 3. Effects of grafting combination and salinity level on the percentage of the different fruit parts: peel, pulp and seeds and on shape index of watermelon fruits.

Grafting combination	Salinity level ($dS \cdot m^{-1}$)	Peel (%)	Pulp (%)	Seeds (%)	Shape index
Nongrafted Tex	2.0	51.33 cd[z]	42.71 ab	5.99 b	0.99
	5.2	53.37 bc	40.86 bc	5.72 c	1.00
Tex/Macis	2.0	55.43 a	38.47 c	6.13 a	0.99
	5.2	50.09 d	44.39 a	6.00 ab	0.97
Tex/Ercole	2.0	54.09 ab	39.63 c	6.29 a	0.96
	5.2	51.12 cd	43.36 a	5.56 c	0.98
Significance					
Grafting combination (G)		NS	NS	NS	NS
Salinity (S)		*	**	*	NS
G × S		**	**	NS	NS

[z]Means within columns separated using Duncan's multiple range test, $p = 0.05$.
[NS,*,**]Nonsignificant or significant at $p < 0.05$ or 0.01, respectively.

Table 4. Effects of grafting combination and salinity level on fruit dry matter, total soluble solids contents, electrical conductivity, pH and titratable acidity of watermelon fruits.

Grafting combination	Salinity level ($dS \cdot m^{-1}$)	Dry matter (%)	Soluble solids (°Brix)	Electrical conductivity ($dS \cdot m^{-1}$)	pH	Titratable acidity (%)
Nongrafted Tex	2.0	9.23 b[z]	10.11 b	4.02 c	5.98 a	0.09
	5.2	10.01 a	10.67 a	4.58 ab	5.57 bc	0.08
Tex/Macis	2.0	9.18 b	9.86 b	4.40 b	5.74 b	0.07
	5.2	10.74 a	11.06 a	4.53 ab	5.63 bc	0.07
Tex/Ercole	2.0	9.38 b	9.81 b	4.47 b	5.74 b	0.08
	5.2	10.45 a	10.61 a	4.82 a	5.51 c	0.07
Significance						
Grafting combination (G)		NS	NS	*	NS	NS
Salinity (S)		***	***	**	***	NS
G × S		NS	NS	NS	NS	NS

[z]Means within columns separated using Duncan's multiple range test, $p = 0.05$.
[NS,*,*,***]Nonsignificant or significant at $p < 0.05$, 0.01 or 0.001, respectively.

Table 5. Effects of grafting combination and salinity level on final leaf area, net assimilation CO_2 (A_{CO_2}) and stomatal conductance (g_s) of watermelon plants.

Grafting combination	Salinity level ($dS \cdot m^{-1}$)	Leaf area (m^2/plant)	A_{CO_2} ($\mu mol\ CO_2/m^2/s$)	g_s ($mmol \cdot m^{-2} \cdot s^{-1}$)
Nongrafted Tex	2.0	0.95 c[z]	25.1 a	324.6 a
	5.2	0.64 d	20.3 cd	192.6 b
Tex/Macis	2.0	2.20 a	23.4 b	328.2 a
	5.2	1.59 b	20.5 c	191.6 b
Tex/Ercole	2.0	2.39 a	21.6 cd	312.0 a
	5.2	1.76 b	19.3 d	202.8 b
Significance				
Grafting combination (G)		***	***	NS
Salinity (S)		**	***	***
G × S		NS	*	NS

[z]Means within columns separated using Duncan's multiple range test, $p = 0.05$.
[NS,*,**,***]Nonsignificant or significant at $p < 0.05$, 0.01 or 0.001, respectively.

the lowest K recorded in ungrafted plants grown in saline solution (Table 6). The concentration of K in all plant tissues, except for fruits, was significantly affected by grafting combination, while salinity level also affected K concentration in roots. Potassium concentration in roots decreased as EC increased. The highest K concentration was detected in stems, followed by leaves and fruits, whereas roots exhibited the lowest K concentration. Among grafting combinations, the highest K concentration was recorded in Tex/Ercole, followed by Tex/Macis and the ungrafted Tex treatment. An opposite trend was observed for the concentration of K in roots.

Na concentration in all plant tissues was significantly affected by salinity level, grafting combination, and salinity × grafting interaction (Table 6), with the highest values recorded on ungrafted plants grown in saline solution. Irrespective of grafting and salinity, Na concentration was lowest in fruits. Concentration of Na in all plant tissue increased as the salinity level in the nutrient solution increased. The concentration of Na in leaves, stems and fruits were highest in ungrafted plants.

Except for fruit, the concentration of Cl in all plant tissues was significantly affected by salinity, but not by grafting combination (Table 6). Concentration of Cl increased as the nutrient solution conductivity increased. The highest Cl concentration was observed in the vegetative parts.

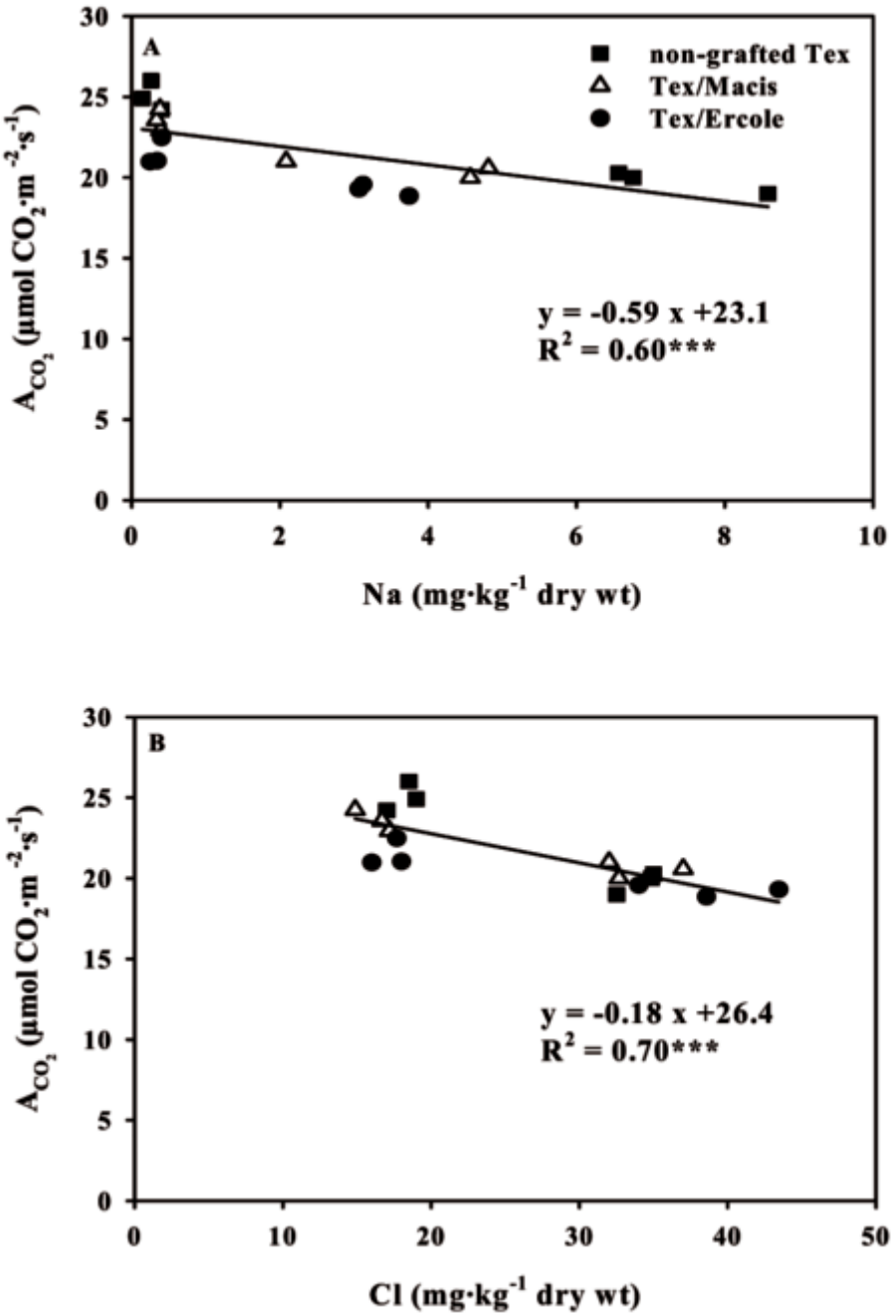

Fig. 1. Relationship between net assimilation of CO_2 (A_{CO_2}) and (**A**) leaf Na concentration (**B**) leaf Cl concentration in all grafting combinations.

Discussion

It is well-established that crop growth and yield decrease with increasing salinity (Maas, 1986; Maas and Hoffman, 1977). Watermelon total fresh yield decreased with salinity, in agreement with many greenhouse studies on melon (Del Amor et al., 1999) tomato (Dorais et al., 2001) and zucchini squash (Rouphael et al., 2006) grown hydroponically. The decrease in yield was mainly attributable to the smaller mean fruit mass in the saline treatment, as the difference in the number of fruits per plant between the two nutrient solutions was not significant. Those results are consistent with the findings of Mendlinger (1994) and Mendlinger and Fossen (1993), who reported for several melon cultivars that increased salinity did not significantly change the number of fruits produced, but decreased the mean fruit mass. Reduced yield under saline treatments could be attributed to NaCl increasing the osmotic potential of the solution as well as the activity of Na^+ and Cl^- ions in the root zone (Greenway and Munns, 1980). Those changes may have affect plant growth and consequently yield through their effects on plant–water relationship, and nutritional abnormalities (Pasternak, 1987).

The higher yield of watermelon from grafted plants observed in this study has been reported earlier on tomato (Fernandez-Garcia et al., 2004) and melon (Ruiz et al., 1997; Ruiz and Romero, 1999). It was demonstrated that grafting per se affects directly plant yield (Neilsen and Kappel, 1996; Rivero et al., 2003b). Its influence can be exerted by the interaction of some or all of the following processes: increase of water and nutrient uptake due to the rootstock's vigorous root system (Lee, 1994; Ruiz et al., 1997), enhanced production of endogenous-hormones (Zijlstra et al., 1994) and enhancement of scion vigor (Leoni et al., 1990). The joint action of some or all of these processes could explain the higher yield in watermelon from grafted plants observed in the current study. The negative effect of increased nutrient solution salinity on total yield was slightly more pronounced in ungrafted (19.6%) than in grafted plants (avg. 16.1%). Those results are consistent with the findings of Edelstein et al. (2005) and Colla et al. (2006) who found that grafting did not reduced losses in melon production caused by salinity. In contrast, Romero et al. (1997) found that grafting mitigated the negative effect of the salinity on the yield of melon plants. These conflicting results may be attributed to different effects of the two *Cucurbita* rootstocks that were used in these studies: TZ-148 was used by Edelstein et al. (2005), P360 by Colla et al. (2006), and Shintoza, RS-841, and Kamel by Romero et al. (1997). In the current study the higher yield recorded with grafting was mainly due to grafting per se.

In general, salinity often reduces the yield of vegetable crops, but in many cases it improves the fruit quality in plants grown in both soil and soilless culture (Francois and Maas, 1994). In the present study, the fruit quality aspects most affected by the different

Table 6. Effects of grafting combination and salinity level on mineral composition of leaves, stems, fruits and roots of watermelon plants.

Grafting combination	Salinity level (dS·m^{-1})	Mineral elements (mg·kg^{-1} of dry mass)											
		K				Na				Cl			
		Leaves	Stems	Fruit	Roots	Leaves	Stems	Fruit	Roots	Leaves	Stems	Fruit	Roots
Nongrafted Tex	2.0	14.8 a[z]	18.6 b	13.0	11.4 a	0.3 c	0.9 c	0.4 b	7.6 c	18.3 b	19.5 b	19.0	19.6 b
	5.2	12.1 b	20.0 b	12.7	8.3 b	7.3 a	14.9 a	3.6 a	19.4 a	33.9 a	32.3 a	19.1	26.1 a
Tex/Macis	2.0	15.9 a	25.5 a	13.4	8.2 b	0.4 c	0.7 c	0.5 b	7.1 c	16.0 b	17.5 b	18.4	15.7 b
	5.2	15.5 a	25.2 a	11.0	3.8 c	3.8 b	3.9 b	1.3 b	17.2 b	33.9 a	33.6 a	17.4	25.1 a
Tex/Ercole	2.0	15.0 a	28.4 a	15.5	9.4 ab	0.2 c	1.2 c	0.6 b	6.0 d	16.4 b	18.2 b	17.9	16.0 b
	5.2	16.1 a	28.4 a	14.9	2.9 c	3.0 b	4.4 b	1.5 b	19.0 a	38.2 a	33.1 a	18.6	23.2 a
Significance													
Grafting combination (G)		***	***	NS	***	***	***	***	*	NS	NS	NS	NS
Salinity (S)		NS	NS	NS	***	***	***	***	***	***	***	NS	***
G × S		*	NS	NS	NS	***	***	***	*	NS	NS	NS	NS

[z]Means within columns separated using Duncan's multiple range test, $p = 0.05$.
[NS,*,***]Nonsignificant or significant at $p < 0.05$ or 0.001, respectively.

salinity concentrations were also those which are particularly important for consumer satisfaction. Increasing solution salinity improved fruit quality by increasing fruit DM, glucose, fructose, sucrose and TSS contents and by decreasing pH. A similar positive effect of salinity on DM, sugar and organic acids was also found in tomato (Dorais et al., 2001 and references cited therein), pepper (Navarro et al., 2002), zucchini squash (Rouphael et al., 2006), and cucumber (Sonneveld and Van der Burg, 1991) grown in soilless culture. Plants acclimate to a saline substrate by increasing the quantity of osmotically active solutes in the tissue (Gorham et al., 1985). The increase in total sugars of watermelon fruits due to salinity may reflect an osmotic adjustment obtained by enhanced synthesis of sugars in the plant tissue (Greenway and Munns, 1980). Nevertheless, Mitchell et al. (1991) indicated that the salt stress influenced osmotic potential and solute content of tomato fruit by reducing water accumulation. There is evidence that *Cucurbita* rootstocks may cause significant deterioration in fruit quality in watermelon cultivars (Lee, 1994; Lee and Oda, 2003). In the present study, the nutritional quality of grafted watermelon such as fruit DM, titratable acids, glucose, fructose, sucrose concentration and TSS contents of grafted watermelons were similar to that of the plants grown on their own roots. Therefore, the use of grafted watermelons under saline conditions would be a potential strategy in increasing total yield and taking advantage of the quality effect of saline water.

The decline in leaf growth is the earliest response of glycophytes exposed to salt stress (Munns and Termaat, 1986) which is accompanied by a decreasing of g_s as reported by Xu et al. (1994) on tomato and by Günes et al. (1996) on pepper. In the present study we observed a decrease of leaf area, net CO_2 assimilation rate and stomatal conductance of grafted and ungrafted watermelon plants by adding NaCl to the nutrient solution. Accumulations of Cl^- and Na^+ in salt stressed leaves were related to reductions in net CO_2 assimilation rate in leaves of grafted and ungrafted plants. It has been proposed that the reduction of leaf gas exchange in response to salinity is due to increase in leaf Na^+ concentration (Garcia-Legaz et al., 1993; Walker et al., 1993). However, other authors associated reductions in photosynthetic capacity and stomatal conductance with high concentrations of Cl^- (Banuls et al., 1997; Garcia-Sanchez et al., 2002). In our experiment, both Cl^- and Na^+ accumulations were responsible of the reduction in net CO_2 assimilation as observed by Martinez-Ballesta et al. (2004) on pepper.

We found the concentrations of Na in leaves were relatively lower for both grafted and ungrafted plants, in comparison to those observed in roots, indicating that transport of Na to leaves was inhibited, which is a typical response of many nonhalophytic plants to NaCl salinity (Graifenberg et al., 1996; Rouphael et al., 2006). Aerial parts of grafted plants had less Na than ungrafted plants. This suggests that grafted plants more efficiently excluded Na transport to leaves. This Na exclusion by the rootstock has been observed in other *Cucurbitaceae* (Graifenberg et al., 1996; Colla et al., 2005). The possible exclusion or reduction in the concentration of Cl was not observed in grafted plants. Romero et al. (1997) reported that the reduction in accumulation of Cl^- ions in grafted melon plants was the main mechanism that reduces the detrimental effect of salinity on plant growth and yield. Thus, it can be concluded that the lack of differences in Cl accumulation between grafted and ungrafted plants, observed in this study, may explain the similarity in response to salinity.

In conclusion, increasing salinity in the nutrient solution decreased total yield by reducing the mean fruit mass, but improved fruit quality by increasing DM, glucose, fructose, sucrose and TSS contents. The grafted plants had reduced leaf Na concentration and not Cl concentration. However, sensitivity to salinity was similar between grafted and ungrafted plants and the higher marketable yield recorded with grafting was mainly due to grafting per se.

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