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Salinity effects on some postharvest quality factors in a commercial tomato hybrid

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SUMMARY

The commercial F1 tomato hybrid (*Lycopersicon esculentum* L. Mill) cv. Radja (GC-793) was cultivated with low (control), moderate (70 mM NaCl) and high (140 mM) salinities under greenhouse conditions for 14 weeks. The effects of different salinity levels on fruit weight and major chemical components determining fruit quality were assessed. Red ripe fruits were harvested to determine fruit weight, size and composition. The water content and mineral composition were determined in whole fruits; the carbohydrate, organic acid and soluble protein contents were analyzed in pericarp tissue. Moderate salinity reduced the fresh and dry fruit weights by only 10 and 13%, respectively, while high salinity reduced them by 40 and 33% compared with control fruits. The water content was not significantly affected by salinity. Thus, fruit weight does not seem to be limited by the water supply under these conditions. The amount of Na^+ significantly increased only at high salinity, while Ca^{2+} and Mg^{2+} contents were not affected. K^+ content, which represents more than 70% of the mineral composition, tends to increase with salinity. The citric acid content slightly increased at moderate salinity, while both citric and malic acids contents were reduced at high salinity, increasing the citric/malic ratio. The pH values were always about 4. The low content in soluble proteins was reduced by high salinity, while moderate salinity increased it. In pericarp tissue of moderately treated fruits, the fructose and glucose contents were three times and twice as high as control and highly salinized-ones. Starch, sucrose and myo-inositol also accumulated under salinity. Hexoses and starch accounted for 20, 66 and 42% of the pericarp dry matter in control, moderate and highly salinized fruits, respectively.

THE fruit yield of a tomato plant is determined by both fruit number and weight. It is well known that salinity decreases tomato yield above 2.5–3 dS m^{-1} of EC in the soil extract. At moderate salinity, fruit yield is more affected by the fruit weight than by their number, while at high salinity, both parameters are affected (Pérez-Alfocea *et al.*, 1990). Some preharvest factors, such as climatic conditions and cultural practices, including soil type and water supply, influence the composition and quality of tomatoes. Tomato flavour is, unquestionably, an important characteristic of fruit quality for the fresh market. This character involves the combination of many chemical constituents such as hexoses and organic acids, which are the major components of soluble solids, being also strongly important for fruit quality and for the processing of concentrates (Young *et al.*, 1993). Soluble sugars and organic acids and their interactions are important for sweetness, sourness and flavour intensity (Schuch, 1993). Fructose and citric acid are more important for sweetness and sourness than glucose and malic acid. When both sugars and acids are low, the result is a tasteless, insipid tomato (Grierson and Kader, 1986). Although the genotype is the main determinant of the sugar and acid contents and, therefore, flavour intensity, fruit

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quality may be improved by increasing the contents of these compounds (Stevens *et al.*, 1977). Thus, light intensity, reduced soil moisture and salt stress increases sugar content, while the acid concentration is related to the potassium content, which can be affected by factors like salinity.

Soluble-solid content is one of the components of yield which shows an inverse relationship wih fresh tomato yield; it is difficult to breed for both characters (Ho and Hewitt, 1986). The characteristic is often used to define economic yield is the product of the fresh yield and solid content, which represents the soluble solid yield per plant (Eshed and Zamir, 1994). Because the sugars and organic acids account for the major portion of the tomato total and soluble solids, most research concerning tomato quality has centred on these components (Young *et al.*, 1993). In this work, the effects of salinity on fruit weight (a component of yield) and on the composition of the major solutes contributing to the solids content and quality are studied in a widely used commercial tomato hybrid, catalogued as tolerant to moderate salinity (Pérez-Alfocea *et al.*, 1996). How does salinity increase tomato fruit quality without a drastic reduction in fruit yield?

MATERIALS AND METHODS

Plant material and culture

The genotype used in this experiment was the commercial F1 tomato hybrid (*Lycopersicon esculentum* L. Mill) cv. Radja (GC-793) supplied by Sluis and Groot Semillas S. A. Seeds were sown in polystyrene boxes with a substrate composed of 50% turf, 25% perlite and 25% siliceous sand. Germination and seedlings establishment were carried out under commercial greenhouse conditions in January 1994. Twenty days after germination, seedlings were transferred to soil in our experimental polyethylene greenhouse. Plants were distributed in nine blocks in a number of 20 plants per block, with a planting pattern of 2 m between rows and 0.5 m between plants within rows. Plants were cultivated with two stems, eliminating all axillary buds. The same amounts of fertilizers were applied to all treatments by a drip irrigation system: 11.9 g N, 15.1 g P_2O_5, 13.1 g K_2O and 0.1 g MgO per plant. Ten days after the transfer of seedlings to soil, the salt treatments were started and applied up to the end of the harvest season. The fertirrigation solutions were prepared in three 2,000 l tanks with water and the salt levels were prepared by adding 70 mM NaCl (moderate) and 140 mM (high salinity) into two of the tanks. The electrical conductivity of the saturated soil extract was measured every 30 d up to the end of the experiment, with the following mean values being obtained: 3.2 ± 0.09 (control), 7.3 ± 0.37 (moderate) and 12.2 ± 1.25 dS m^{-1} (high salinity). Each salt treatment was randomly applied to three blocks, with 60 plants per treatment.

Fruit harvesting

Mature red fruits were weekly harvested from the second truss (due to the lack of homogeneity in the first truss) and up to the end of the experiment (end June). Approximately 14 weeks after the beginning of the salt treatments, red ripe fruits were randomly harvested from different plants and trusses for analysis. Among other variates, fruit weight and size were measured; carbohydrates, organic acids and soluble proteins were analyzed in pericarp tissue; water content, mineral composition and pH were determined in whole fruits. The pericarp tissue was cut into small pieces, and samples of two grams were frozen with liquid nitrogen and stored at −20°C until analysis. Three replicates (combination of three fruits per replication) were carried out for each treatment.

Fruit analysis

Samples of pericarp tissue were homogenized on ice with a Polytron in 10 ml of 50 mM HEPES-KOH (pH 6.8) extraction buffer. The homogenate was centrifuged at 15,000 rpm at 0°C for 15 min. Soluble carbohydrates, organic acids and soluble proteins were analyzed in the supernatant, while the starch content was determined in the pellet. The soluble proteins were measured using Bradford reagent (Bradford, 1976) and bovine serum albumin as standard.

For soluble carbohydrate analysis (fructose, glucose, sucrose and myo-inositol), 0.2 ml of the supernatant was purified by passing it through a cation exchange resin (Dowex 50W 50X8-400 H^+-form, from Sigma Chemicals) and an anion exchange one (Dowex 1-X8 COO^- form, from Bio-Rad). The purified extract was filtered by 0.45 μm Millipore filters (Waters) and injected into a Shimadzu HPLC system composed of an isocratic pump (LC-6A), a RI Detector (RID-6A), and a column Tracer Carbohydrate Spherishorb NH_2 5 μm. The analyses were performed at 45°C using acetonitrile:water (69:31, V/V) as phase mobile at a flow rate of 1ml min^{-1}. Quantification of sugars was made by the external standard method (Pérez-Alfocea and Larher, 1995). For organic acids, the crude extract was directly filtered by 0.45 μm and analyzed by HPLC, using a column Interaction ORH-801, an UV detector (SPD-6AV) at 210 nm, a phase mobile with H_2SO_4 0.01 N at a flow rate of 0.6 ml min^{-1} and at 45°C. The pellet was washed three times with 70% ethanol and incubated with 10 ml of 35% perchloric acid overnight to hydrolyze starch (Wang *et al.*, 1993), whose content was determined by the anthrone reagent using glucose as standard.

Water content was obtained by the formula (FW-DW)/FW, where FW and DW are the fresh and dry weight, respectively. The dry weight was determined by placing the fruits in a oven at 70°C up to a constant weight (Pérez-Alfocea *et al.*, 1993). The individual fresh fruit weight was calculated considering the global production along the harvest period and the dry fruit weight was calculated taking into account the fresh weight and the fruit water content measured in nine fruits. For mineral composition and pH determination, whole fruits were homogenized with a domestic mixer. The pH was directly measured in the fruit homogenate, while the analysis of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) was carried out in the nitric-perchloric (2:1) digestion of 1 g of the fruit homogenate without seeds, using a Shimadzu AA-680 Flame Emission Atomic Absorption Spectrophotometer (Pérez-Alfocea *et al.*, 1993). Analysis of variance was performed according to SYSTAT standard methods.

RESULTS

Fruit weight, water content and size

Considering the global production, the fresh fruit weight was reduced by 10% and 40% under moderate and high salinity, while the dry fruit weight was decreased by 13 and 33%, respectively, (Table I). However, the fruit water content was not significantly different in control and salinized fruits, although it was reduced in highly salinized fruits compared with moderately treated ones. The equatorial diameter of salinized fruits was also reduced between 6 and 16% compared with control fruits, but only high salinity changed the commercial grades from MM (45–57 mm) up to MMM (<47 mm) (Table I).

Mineral composition

Potassium was the major nutrient in tomato fruits, and its content represented more than 70% of the total cations. This content trends to increase with salt stress, and a maximum of 560 mmol kg^{-1} dry weight was found at high salinity (Figure 1). Sodium was significantly accumulated only at high salinity, reaching up to three times more (18% of the total cations) than in the control fruits. Calcium and magnesium contents were not affected by the stress.

Acidity

The citric and malic acids were the more abundant organic acids in pericarp tissue and their contents were reduced by 24 and 41% under high salinity, respectively (Figure 2). The citric acid contents were 2–3 times higher

TABLE I

Fresh (FW) and dry weights (DW), water content (WC) and equatorial diameter (ED) of whole mature red fruits from tomato plants treated with 0 (control), 70 and 140 mM NaCl added to the nutrient solution. Each value is the mean of three replications ± SE

Treatment	FW (g)	DW (g)	WC (% FW)	ED (mm)
Control	76.5 ±2.3	6.73 ± 0.2	91.2 ± 0.6	54.9 ± 3.0
70 mM NaCl	69.1 ± 2.3	5.87 ± 0.5	91.5 ± 0.1	51.7 ± 1.8
140 mM NaCl	45.3 ± 3.2	4.53 ± 0.3	90.0 ± 0.6	46.1 ± 3.3

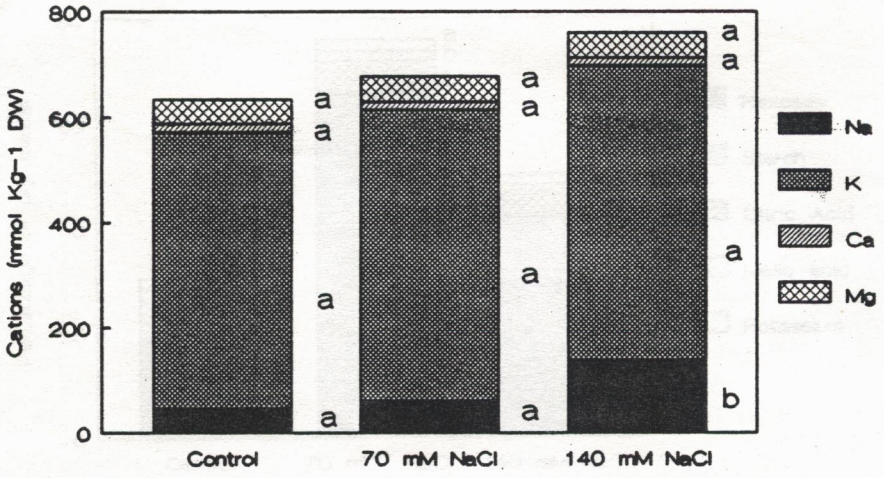

FIG. 1
Na^+ K^+, Ca^{2+} and Mg^{2+} contents in mature red fruits from plants treated with 0 (control), 70 and 140 mM NaCl added to the nutrient solution. Each value is the mean of three replications. For each cation, different letters between treatments indicate that differences differ significantly at 5%.

than the malic acid ones. As the last was more affected by salinity, the citric/malic ratio increased from 2.7 (control) up to 3.5 (140 mM NaCl). The pH of the whole fruit was always about 4.

Soluble proteins

The content of soluble proteins in pericarp of ripe tomato was never higher than 8 mg kg^{-1} of dry weight; it was reduced by 40% under high salinity and increased by 60% under moderate salinity on the dry weight basis (Figure 3).

Carbohydrate content

The hexose content in pericarp tissue at moderate salinity was three times and twice as great as in control and highly salinized ones, reaching up to 3,000 mmol kg^{-1} of dry weight in these conditions (Figure 4). The starch

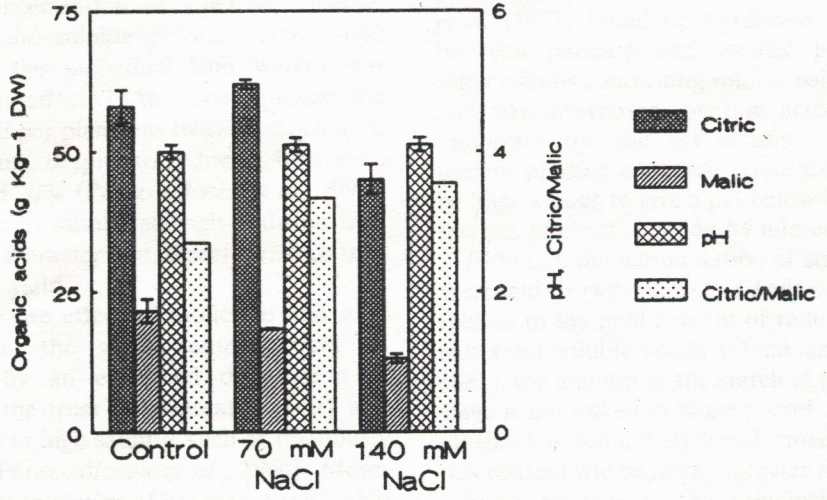

FIG. 2
Citric and malic acids contents and citric/malic ratio in pericarp tissue, and pH values of mature red fruits from plants treated with 0 (control), 70 and 140 mM NaCl added to the nutrient solution. Each value is the mean of three replications ± SE.

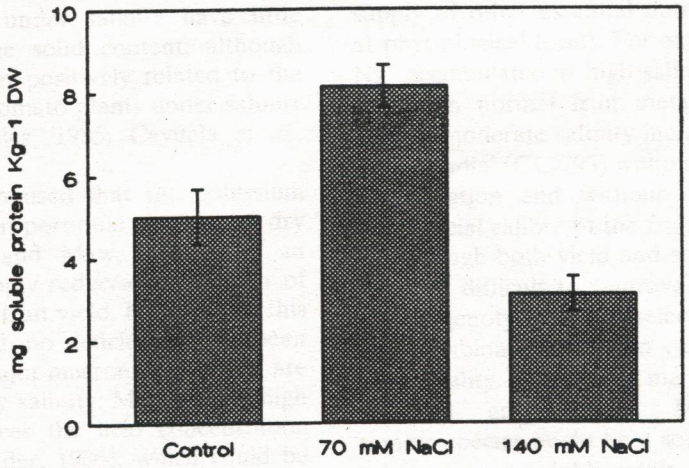

Fig. 3
Soluble protein content in pericarp tissue of mature red fruits from plants treated with 0 (control), 70 and 140 mM NaCl added to the nutrient solution. Each value is the mean of three replications ±SE.

content increased with salinity and 690 mmol of glucose per kg of dry weight were found in highly salinized fruits. The myo-inositol accumulated in salt-treated fruits (45–65 mmol kg^{-1} DW) and sucrose was detectable only at high salinity (30 mmol kg^{-1} DW).

Dry-matter composition

The hexoses accounted for 17% and 56% of dry weight in pericarp of control and moderately salinized fruits, while starch accounted for between 3.8% (control) and 12.5% (highly salinized fruits) (Figure 5). The citric and malic acids were the major organic acids and accounted for 8% (control and moderate) and 5.8% (high salinity). Potassium was the main mineral nutrient; it represented about 2% of the dry matter.

Discussion

According to the results obtained, salinity mainly increases the tomato fruit quality of the F1 tomato hybrid 'Radja' (GC-793) by increas-

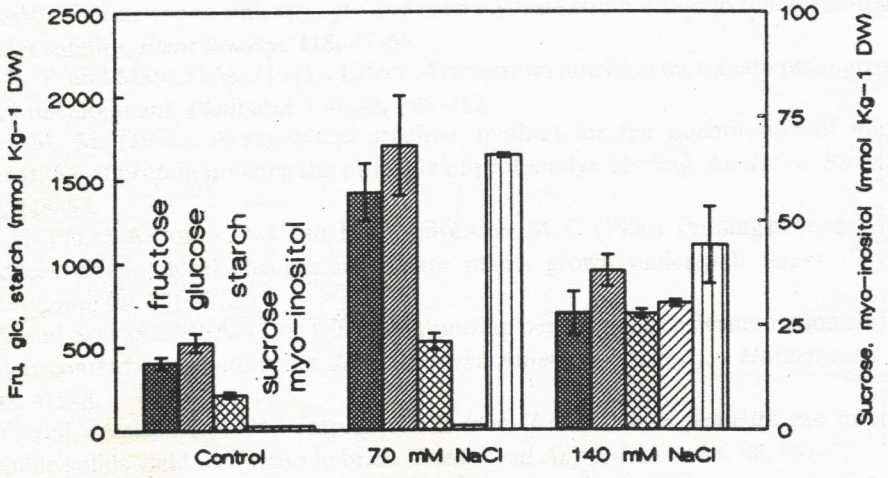

Fig. 4
Fructose, glucose, starch (expressed as glucose) (left y-axis), sucrose and myo-inositol (right y-axis) contents in pericarp tissue of mature red fruits from plants treated with 0 (control), 70 and 140 mM NaCl added to the nutrient solution. Each value is the mean of three replications ±SE.

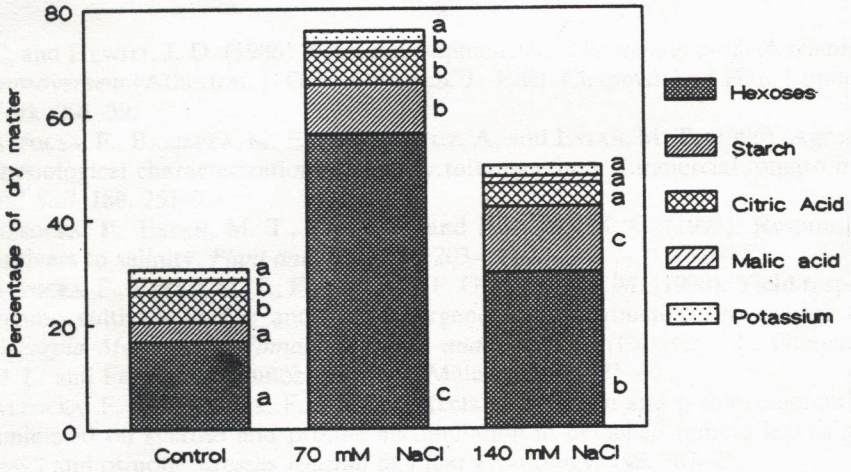

FIG. 5
Dry-matter composition of pericarp tissue of mature red fruits from plants treated with 0 (control), 70 and 140 mM NaCl added to the nutrient solution. For each component, different letters between treatments indicate that differences differ significantly at 5%.

ing the carbohydrate concentration (soluble and insoluble), but also by increasing the citric/malic ratio, since citric acid is more important for sweetness and sourness than is malic acid (Grierson and Kader, 1986). Quite similar results has been described in strawberry cultivated under saline conditions (Awang and Atherton, 1995). The best quality attributes on postharvest tomatoes were obtained under moderate saline conditions, because the greatest concentration of fructose, glucose, citric acid and soluble proteins were found there, and the individual fruit weight was practically unaffected. As a consequence, the hexose yield per plant was twice as much as in control plants, despite to reducing fruit yield by less than 20% (Pérez-Alfocea *et al.*, 1996). However, high salinity strongly reduced fruit weight and diameter and, therefore, both fruit and hexose yield.

The opposite effect of moderate and high salinities on the sugar content could be explained by an enhanced distribution of sucrose to the truss at moderate salinity and a reduction at high salinity, such as previously reported (Pérez-Alfocea *et al.*, 1996). Moreover, the accumulation of hexoses in the highly salinized fruits (compared with control fruits) may be due to a decrease in the use of sugars for growth (Balibrea *et al.*, 1996).

A high sugar and relatively high acid concentration are required for the best flavour for fresh market tomatoes, and an increase in any of these compounds is important for the quality of industrial processing by increasing the solids content (Young *et al.*, 1993). Sugars, mainly glucose and fructose, account for about half of the dry matter or 65% of the total soluble solids of a ripe tomato fruit (Winsor, 1966), and they are mainly concentrated in the pericarp (Grierson and Kader, 1986). Stevens *et al.* (1977) found no significant differences between pericarp and locular portions of tomato fruits concerning soluble solids content and pH. Moreover, organic acids are also important for the preservation of canned tomato product and their concentration must be high enough to give a pH below 4.4 to avoid the risk of contamination by microorganism.

Although the accumulation of starch during the rapid growth period of fruit seems to be related to the final content of reducing sugars and total soluble solids (Dinar and Stevens, 1981), the amount of the starch at the red ripe stage is not linked to hexose level, and even if all starch is definitively transformed in hexose, this content will be always greater at moderate salinity. Sucrose is the principal assimilate imported and its metabolism is important for fruit growth, but the sucrose content remains low in the fruit. The accumulation of sucrose

and myo-inositol under salinity have little importance for the solid content, although the latter has been positively related to the growth ability of tomato plants under salinity (Sacher and Staples, 1985; Cayuela *et al.*, 1996).

It has been proposed that the potassium accumulation is proportional to that of dry matter (Besford and Maw, 1975) and an insufficient K^+ supply reduces the number of fruits and thereby fruit yield. However, in this commercial hybrid, no deficiencies has been observed in the major macronutrients that are usually affected by salinity. Moreover, a high K^+ supply enhances the acid concentration (Grierson and Kader, 1986), which could be related to electroneutrality maintenance. In this experiment, high salinity increased the total cation content (mainly due to Na^+ accumulation), but a significant decrease in organic acids content was registered, probably due to metabolism disturbances.

Fruit weight reduction and high sugar content cannot be explained by water deficiency, and it is more likely that the factor limiting fruit growth under salinity is the supply of other essential nutrients (probably at physiological level). For example, the high Na^+ accumulated at high salinity might interfere with normal fruit metabolism. In this regard, moderate salinity increases fruit quality in 'Radja' (GC-793) without additional Na^+ accumulation and without changes in the commercial calibre of the fruit.

Although both yield and soluble-solid content are difficult to improve simultaneously, tomato genotypes can be selected to obtain the best combination between yield and postharvest quality to exploit marginal soils and salinized ground-water. Moreover, wild tomato species might be a source of both salt tolerance and soluble-solids content in cultivated tomatoes.

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