Tomato yield and quality as affected by nitrogen source and salinity

Pilar Flores, Josefa Navarro, Micaela Carvajal, Antonio Cerdá, Vicente Martínez

Agronomie 23 (2003) 249–256

DOI: 10.1051/agro:2002088

Original article

Tomato yield and quality as affected by nitrogen source and salinity

Pilar FLORES, Josefa María NAVARRO, Micaela CARVAJAL, Antonio CERDÁ, Vicente MARTÍNEZ*

Dpto. Nutrición y Fisiología Vegetal. Centro de Edafología y Biología Aplicada del Segura CSIC, PO Box 4195, 30080 Murcia, Spain

(Received 10 April 2002; accepted 2 July 2002)

Abstract – Tomato plants cv. Daniela were grown in a nutrient solution containing 0, 30 and 60 mM NaCl and fertilized with 14/0, 12/2 and 10/4 NO_3^-/NH_4^+ mM ratio to determine the effect of salinity and nitrogen source. Salinity in general reduced the total tomato fruit yield regardless of nitrogen source. However, no yield reduction was observed for nitrate-fed plants in the presence of 30 mM NaCl. Increasing NH_4^+ concentration in the nutrient solutions decreased tomato yield. The highest yield was found in the first trusses for all treatments, except when plants were grown with a 12/2 NO_3^-/NH_4^+ mM ratio until the set of the third truss and after that transferred to a nutrient solution with NO_3^- as the only nitrogen source. The increase in salinity and NH_4^+ concentration in the nutrient solutions increased fruit quality by increasing the content of sugars and organic acids. However, the increase in fruit quality was associated with a decrease in yield.

nitrate / ammonium / salinity / yield / quality

Résumé – **Effet de la source d'azote et de la salinité sur le rendement et la qualité de la tomate.** Des plants de tomates cv. Daniela ont été cultivés dans une solution nutritive contenant 0, 30, et 60 mM NaCl et fertilisés avec 14/0, 12/2 et 10/4 mM NO_3^-/NH_4^+ dans le but d'étudier l'effet de la salinité et de la source d'azote apportée. Dans tous les cas, sauf pour les plantes fertilisées avec du nitrate en présence de 30 mM NaCl, la salinité entraîne une diminution du rendement total, quelle que soit la source d'azote. L'augmentation de la concentration en NH_4^+ dans la solution nutritive entraîne une diminution du rendement. Le rendement le plus élevé a été observé dans les premières grappes pour tous les traitements, sauf pour les plantes cultivées dans une solution contenant un rapport NO_3^-/NH_4^+ de 12/2 jusqu'à l'apparition de la troisième grappe puis transférées dans une solution nutritive avec NO_3^- comme seule source d'azote. L'augmentation de la salinité et de la concentration en NH_4^+ dans la solution nutritive entraîne une meilleure qualité des tomates. Ceci est dû à l'augmentation du taux de sucres et d'acides organiques dans les fruits. Cependant, cette amélioration de la qualité est accompagnée par une chute de rendement.

nitrate / ammonium / salinité / rendement / qualité

1. INTRODUCTION

Tomato crops are widely grown in greenhouses, in arid and semiarid regions, where normally only saline water is available for crop irrigation. Salinity has a negative effect on tomato yield because it decreases fruit weight [24] and marketable yield [22]. Total fruit number per plant has also been observed to decrease under salinity, at high electrical conductivity values such as 9 $dS \cdot m^{-1}$ [27]. Ehret and Ho [7] concluded that the effect of salinity on tomato fruit size is due to a reduction in water content rather than in dry matter accumulation. Nevertheless, a beneficial effect of salinity on fruit quality has been documented [1]. Salt improves quality by enhancing flavor and the sugar, total soluble solids, and acid contents [19, 26], without affecting shelf life [4]. A higher starch concentration during early fruit development was also found to be a precursor of higher sugar content in the mature fruit treated with saline water [11]. The effect of salinity on fruit physical characteristics has also been studied by many authors [6, 19, 23], as a quality parameter. The fact that at low salt concentration development of fruits is not significantly different from that of non-saline grown plants, but quality is enhanced, has been used to improve quality without decreasing yield in tomato culture [16, 17].

Many studies have been carried out with young plants to determine the effect of NO_3^- and/or NH_4^+ nutrition on growth and metabolism [3, 8]. Fertilizers containing both NO_3^- and NH_4^+ are generally recommended for tomato production because vegetative growth is maximized, which is thought to increase fruit yield [10]. Ammonium, as the sole N-source, decreased plant growth with respect to nitrate-fed plants [20]. A NO_3^- and NH_4^+ combination produced greater vegetative

Communicated by Peter Barraclough (Harpenden Herts, UK)

* Correspondence and reprints
vicente@cebas.csic.es

growth than when either N-form was used alone [10]. Few studies have been done with NO_3^- and NH_4^+ combinations in order to determine their effect on tomato yield. Hartman et al. [13] found that the presence of NH_4^+ reduced fruit weight and increased the incidence of blossom-end rot in fruits. However, the greatest vegetative growth was produced when 25% of nitrogen was applied as NH_4^+. They suggested that vegetative and reproductive growth were affected differently by the form of N-nutrition.

Salinity also has a big influence on N-assimilation. Martínez et al. [15] described alterations in N-compounds for tomato plants under saline stress. They found a more significant increase in proline, induced by salinity, when plants had been exposed to NO_3^- plus NH_4^+ than when they had been fed with NO_3^- alone. Feng and Barker [9] showed that application of NH_4^+ to tomato plants under saline stress increased toxic symptoms expressed as chlorosis and necrosis. However, little is known about the effect of N-form combined with saline water, in the nutrient solution, on fruit quality.

The objective of this study was to determine the influence of three salinity levels and three NO_3^-/NH_4^+ mM ratios in nutrient solutions on yield and fruit quality of greenhouse tomatoes.

2. MATERIALS AND METHODS

2.1. Growth conditions and experimental procedures

The experiment was carried out under greenhouse conditions, in the fall to winter season, with an average temperature of 25 °C and a photoperiod of 14/10 h day/night at the beginning, and 20 °C and 15/9 h day/night at the end of the experiment. Seeds of tomato (*Lycopersicon esculentum* Mill. cv. Daniela) were sown in vermiculite and moistened with 1/10 strength Hoagland nutrient solution for 20 days. Seedlings were transferred to 120 l tanks containing aerated Hoagland solution, modified in order to obtain three NO_3^-/NH_4^+ mM ratios (14/0, 12/2 and 10/4) by using KNO_3, $Ca(NO_3)_2$ and/or NH_4Cl. The solutions were made using deionized water. In all treatments the concentration of N was maintained at 14 mM. In order to maintain constant concentrations of Ca^{2+} and K^+ in all nutrient solutions, $CaCl_2$ and K_2SO_4 were added as needed. Salinity treatments started 14 days after transplanting and consisted of three NaCl levels (0, 30 and 60 mM). Salt was added on two consecutive days for the 60 mM level in order to avoid an osmotic shock. Treatments with the 12/2 ratio and three salinity levels were duplicated, to allow transfer of one replicate to the 14/0 ratio when the 3rd truss had set. This treatment is represented by 12/2 +14/0. There were twelve treatments distributed in four randomized blocks (one replicate per block). The pH of each nutrient solution was adjusted to between 5.5 and 6.0 every day. Water lost by transpiration was replaced every two days and nutrients were added every week to restore their initial concentrations. Trusses above the 5th one were removed, and leaves were allowed to grow until the end of the experiment. Eight fruits per truss were left (discarding the others), then collected at ripening and weighed to determine mean fruit weight and total fruit yield.

2.2. Selection, preparation and sample analysis

Whole fruit firmness and tissue firmness were determined in two selected fruits with intact skin and uniform color per plant (eight per treatment), from the 2nd truss. These assays were performed with a universal assay machine (Lloyd LR 5K Instrument). Whole fruit firmness was determined by compressing fruit to 5% deformation. Two opposite sides of each tomato were used and the results were expressed in $N \cdot mm^{-1}$. The Magness-Taylor test was carried out using a 5 mm probe to determine tissue firmness, with and without peel, on two equatorial zones (at 90° to each other) of each fruit. The equipment was set up to travel at 20 $mm \cdot min^{-1}$ for 12 and 5 mm, respectively, after contacting the fruit surface. Results were expressed in N. Color was measured with a Minolta CR300 colorimeter and the value for each fruit was the average of three measurements.

Fruit quality parameters were determined in tomatoes from the 2nd and 5th trusses. Thirty-two fruits per treatment (4 fruit per truss × 2 trusses per plant × 4 plants per treatment) were selected, and cut in two. One half was liquefied and filtered for pH, total soluble solids content (TSS), acidity, reducing sugars and organic acid determinations. The other half was frozen at –20 °C and lyophilized to allow determination of the ionic composition. TSS was determined by an Atago N1 refractometer and expressed as ºBrix at 20 °C. Acidity was analyzed by potentiometric titration with 0.1 M NaOH to pH 8.1 using 15 ml of juice. Sugars were quantified by HPLC (Merck Hitachi), with a LiCrospher 100 NH_2 5 µm column and refraction index detector. The mobile phase was acetonitrile:water (85:15) with a flow rate of 1.5 $ml \cdot min^{-1}$. Organic acids were determined by gas chromatography with a flame ionization detector, following derivation with MTBSTFA [18]. The derivatized mixtures were injected into a Shimadzu GC-14A gas chromatograph fitted with a capillary SPB-5 column (Supelco), 30 m length, 0.25 mm id. The carrier gas used was helium and the column temperature was programmed from 60 to 150 °C at 20 $°C \cdot min^{-1}$ and from 150 °C to 300 °C at 6 $°C \cdot min^{-1}$. For cations, a HNO_3-$HClO_4$ (2:1) digestion was carried out and Na^+ and K^+ were determined by emission and Ca^{2+} and Mg^{2+} by atomic absorption with a Perkin-Elmer 5500 spectrometer. Anions were extracted with water and determined by Chromatography using conductivity detection (Dionex DX-100) and an Ionpac AG12A guard column and an Ionpac AS12A analytical column. The mobile phase was 2.7 mM Na_2CO_3/0.3 mM $NaHCO_3$.

Data were statistically analyzed using the SPSS 7.5 software package, by ANOVA and by Tukey's Multiple Range Test, to determine differences between means.

3. RESULTS

Salinity reduced the total tomato fruit yield regardless of the NO_3^-/NH_4^+ mM ratio (Fig. 1). For the control treatment (0 mM NaCl) no reduction in fruit yield was observed for the 12/2+14/0 treatment compared with 14/0 plants. Increasing salinity from 0 to 30 mM NaCl reduced yield by 6% and 30% for the 14/0 and 10/4 treatments, respectively. However, when

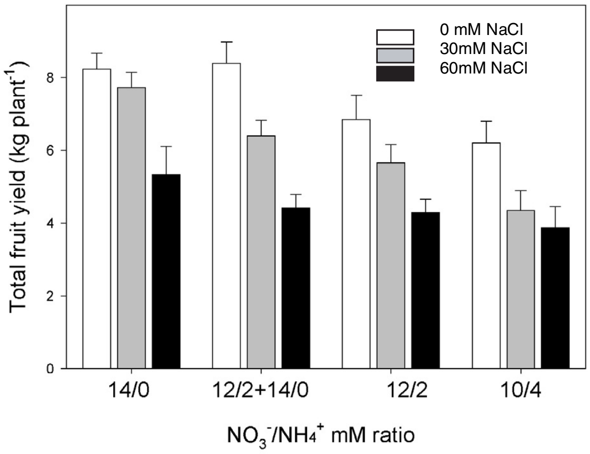

Figure 1. Total fruit yield of plants treated with different salinity levels (0, 30 and 60 mM NaCl) and NO_3^-/NH_4^+ mM ratios (14/0, 12/2 +14/0, 12/2 and 10/4). Values are means of four replicates (± SE).

salinity was increased from 30 to 60 mM NaCl, fruit yield was reduced by a further 31% for 14/0 plants and by 11% for 10/4 plants. Increasing the NH_4^+ concentration decreased total fruit yield in all the salinity treatments.

Salinity treatment and source of nitrogen significantly affected mean fruit weight (Tab. I). Supplying 30 mM NaCl reduced the mean tomato weight by 20%, whilst 60 mM NaCl reduced the mean weight by around 42%. Increasing NH_4^+ concentration decreased the mean fruit weight, thus the greatest fruit size was obtained when all the nitrogen was applied as NO_3^-. The first trusses produced larger tomatoes than the last ones. The 12/2+14/0 treatment was the only one able to maintain fruit size throughout the experiment, since no significant difference (student's t-test) was found between trusses 1–3 and trusses 4–5 (data not shown).

Increasing salinity and NH_4^+ significantly increased TSS, acidity, vitamin C, citric acid and malic acid and decreased pH in the juice of fruit from truss 2 (Tab. II). In all treatments, fruit from truss 5 had higher concentrations of vitamin C, citric and malic acids and TSS than fruits from truss 2. Fruits from truss 2 of the 0 mM NaCl and 14/0 treatments had the lowest TSS and organic acids content, except for malic acid. For this organic acid, the treatment producing the lowest concentration was 30 mM NaCl and the 12/2 NO_3^-/NH_4^+ mM ratio. Fruits with the highest concentrations of TSS and organic acids belonged to truss 5 (10/4 NO_3^-/NH_4^+ mM ratio and 60 mM NaCl treatments). However, in the 10/4 treatments, no significant differences between salinity treatments were found with respect to TSS and organic acids. The concentration of citric acid in the tomato fruits was around ten times higher than for malic acid, although the highest concentration corresponded to vitamin C.

Only fructose and glucose were detected in the sugar analyses of the tomato juice. For all treatments, plant age was the factor that most increased sugar concentration (Fig. 2). The sugar concentration in the juice of fruit from the 5th truss was around 65% higher than from the 2nd truss. Supplying 60 mM NaCl significantly increased the concentrations of fructose

Table I. Mean fruit weight for the first three trusses (1-3), the last two trusses (4-5) and all trusses (1-5) for tomato plants treated with three different salinity levels (0, 30, and 60 mM NaCl) and three NO_3/NH_4 mM ratios for different periods.

		Mean fruit weight (g)		
MAIN EFFECT		trusses 1-3	trusses 4-5	trusses 1-5
Salinity level (mM NaCl)	0	224c	184c	212c
	30	177b	156b	170b
	60	133a	105a	123a
		***	***	***
Nitrogen (NO_3/NH_4 ratio)	14/0	211c	176b	200b
	12/2 +14/0	185bc	178b	183b
	12/2	162ab	119a	149a
	10/4	152a	104a	135a
		***	***	***
SALINITY × NITROGEN				
NO_3/NH_4 ratio	mM NaCl			
14/0	0	256	156bcd	226
	30	241	218de	225
	60	171	129abc	157
12/2+14/0	0	231	233e	232
	30	193	182cde	190
	60	130	121abc	126
12/2	0	213	167bcd	202
	30	156	123abc	145
	60	130	91a	117
10/4	0	204	136abc	184
	30	148	102ab	132
	60	114	85a	103
		n.s.	*	n.s.

*, ** and ***, significant differences between means at the 5, 1 and 0.1% levels of probability, n.s., non-significant at $P = 5\%$. Different letters in the same column indicate significant differences between salinity levels, nitrogen treatment and salinity × nitrogen, respectively, at the 5% level of probability.

and glucose, especially in the 14/0 and 10/4 treatments. The highest concentrations of glucose and fructose in trusses 2 and 5 were found in the 10/4 and 60 mM NaCl treatments and the lowest in the 14/0 and control treatments.

Treatments not only affected the chemical composition of tomato fruits, but also physical properties related to fruit quality. Figure 3 shows the firmness measured by three different analytical methods. Salinity significantly decreased

Table II. Effects of salinity and NO_3/NH_4 ratio on TSS, pH, acidity, organic acids and vitamin C of tomato fruit juice.

MAIN EFFECT		truss num.	TSS (ºBrix)	pH	acidity (%citric acid)	vitamin C (mM)	malic acid (mM)	citric acid (mM)
Salinity level (mM NaCl)	0	2nd	5.4a	4.31c	0.35a	69a	1.7a	23.0a
	30		5.6a	4.25b	0.40a	73a	1.6a	26.2b
	60		6.5b	4.16a	0.49b	86b	1.9b	31.8c
			***	***	***	***	**	***
	0	5th	6.6a	4.24a	0.41a	139	2.9	41.9
	30		7.2a	4.22ab	0.44a	136	3.0	39.8
	60		9.0b	4.14b	0.67b	117	3.1	39.2
			***	**	***	n.s.	n.s.	n.s.
Nitrogen (NO_3/NH_4 ratio)	14/0	2nd	5.2a	4.35b	0.35a	69a	1.8bc	25.6a
	12/2+14/0		5.7ab	4.29b	0.39ab	77ab	2.0c	29.1b
	12/2		6.2b	4.18a	0.45b	70a	1.5a	24.9a
	10/4		6.1b	4.16a	0.44ab	87b	1.7b	28.2ab
			**	***	*	***	***	**
	14/0	5th	6.6a	4.32c	0.42a	106a	3.0a	32.3a
	12/2+14/0		6.8a	4.24bc	0.44a	128ab	2.8a	37.2ab
	12/2		8.6b	4.12a	0.59b	132ab	2.8a	43.0bc
	10/4		8.2b	4.14ab	0.57b	152b	3.6b	47.2c
			***	***	***	*	***	**
SALINITY × NITROGEN								
NO_3/NH_4 ratio	NaCl (mM)							
14/0	0	2nd	4.8a	4.42	0.30a	63a	1.7abcd	22.0ab
	30		5.2ab	4.35	0.35a	69a	1.8bcde	25.2ab
	60		5.6ab	4.28	0.40ab	73a	1.9cde	29.6bc
12/2+14/0	0		5.0a	4.39	0.31a	69a	1.9cde	26.0abc
	30		5.2ab	4.31	0.36a	81a	2.0de	28.2bc
	60		6.8bc	4.17	0.51ab	82a	2.1de	33.1cd
12/2	0		6.4abc	4.22	0.44ab	74a	1.8bcde	24.2ab
	30		6.3abc	4.19	0.48ab	65a	1.2a	24.9ab
	60		6.0abc	4.14	0.43ab	72a	1.4abc	25.6abc
10/4	0		5.2a	4.24	0.34a	66a	1.4abc	19.5a
	30		5.4ab	4.16	0.38ab	77a	1.3ab	26.3abc
	60		7.5c	4.08	0.59b	115b	2.2e	38.2c
			**	n.s	*	***	***	***
14/0	0	5th	5.8a	4.37	0.31a	101a	2.1a	26.9a
	30		6.0a	4.35	0.34a	122ab	3.3b	37.1abc
	60		8.1cd	4.26	0.62de	98	3.6b	32.9ab
12/2+14/0	0		5.8a	4.28	0.40abc	107ab	2.8ab	30.9ab
	30		6.4ab	4.25	0.36ab	138ab	2.8ab	39.5abc
	60		8.5bcd	4.19	0.58cd	139ab	2.7ab	41.7abc
12/2	0		8.0abcd	4.12	0.55bcd	159ab	3.1ab	50.2bc
	30		8.8cd	4.12	0.60cd	126ab	2.6ab	36.5abc
	60		8.9bcd	4.13	0.63de	111ab	2.6ab	42.1abc
10/4	0		6.7abc	4.23	0.37ab	180b	3.6b	55.6c
	30		6.9abc	4.17	0.36ab	162ab	3.6b	47.4abc
	60		10.3c	4.04	0.81e	115ab	3.7b	38.5abc
			*	n.s.	**	*	**	**

*, ** and ***, significant differences between means at the 5, 1 and 0.1% levels of probability, n.s., non-significant at $P = 5\%$. Different letters in the same column indicate significant differences between salinity levels, nitrogen treatment and salinity × nitrogen, respectively, at the 5% level of probability.

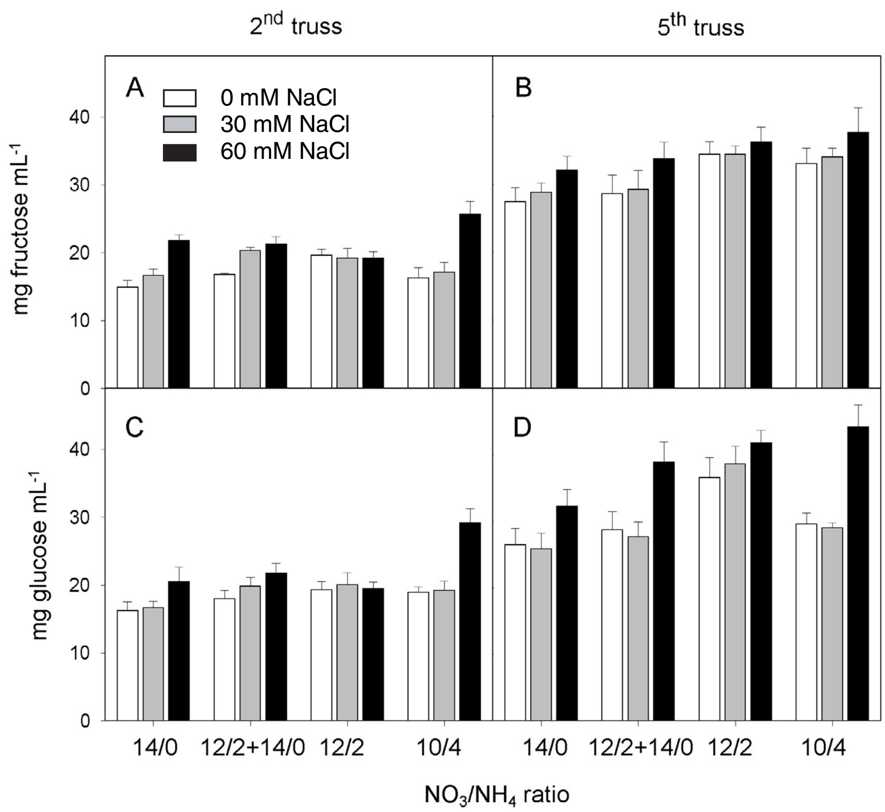

Figure 2. Fructose (A and B) and glucose (C and D) contents in juice of tomatoes as affected by salinity (0, 30 and 60 mM NaCl) and different NO_3^-/NH_4^+ mM ratios (14/0, 12/2+14/0, 12/2 and 10/4). Figures A and C correspond to the 2nd truss and B and D to 5th truss. Values are means of four replicates (± SE).

the whole fruit firmness (Tab. III). However, salinity increased tissue firmness when it was measured both with and without peel. These two parameters were also decreased by the increasing NH_4^+ concentration. The greatest differences between treatments were found when tissue firmness was measured with peel. Tomato fruit from the control and 14/0 exhibited the lowest values of tissue firmness.

Salinity significantly increased Cl^- and Na^+ concentrations in the tomato juice (Tab. III). However, the concentration of Cl^- in control fruits was 5 times higher than the concentration of Na^+, and for the 60 mM NaCl treatment it was about 3 times higher. On the contrary, salinity significantly decreased the Ca^{2+} concentration of the fruit. Increasing the NH_4^+ concentration in the nutrient solution led to a significant decrease in Ca^{2+}, an increase in Cl^- concentration, and slight decreases in K^+ and Mg^{2+}. The combination of salinity (60 mM) + NH_4^+ (10/4) reduced the Ca^{2+} concentration by two thirds with respect to the control + 14/0 treatment. No significant differences were found for sulphate, phosphate and total nitrogen between treatments.

4. DISCUSSION

Salinity reduced total fruit yield (Fig. 1) by reducing mean fruit weight (Tab. I). Similar results were found by other authors [4, 22, 24, 26]. Although some authors reported a decrease in fruit number at high salinity [5, 27], in our experiment no significant difference was found in the number of fruits per plant, due to our practice of discarding fruit until eight per truss were left. Moderate salinity (30 mM NaCl) did not significantly affect the fruit yield of nitrate-fed plants. Similar results were found by Mitchell et al. [16] and Mizrahi et al. [17] for tomato plants. Ehret and Ho [7] also found that the reduction of tomato fruit production by salinity was proportional to the reduction of plant vegetative growth.

Under non-saline conditions, the addition of NH_4^+ at the beginning of the experiment (12/2+14/0) did not negatively affect the fruit yield. However, under saline conditions (30 or 60 mM NaCl) the application of NH_4^+, even for a short time, decreased the yield of tomato plants. Hartman et al. [13] reported an increase in vegetative growth of tomato plants by NH_4^+ addition, although fruit weight was reduced when NH_4^+ constituted any part of the N supply. Plants grown with the 12/2 +14/0 treatment showed greater vegetative growth than plants grown with NO_3^- alone (data not shown). In the 12/2+14/0 treatment, average fruit weight also remained constant from the first three to the last two trusses.

This may suggest a greater potential of the ammonium-fed plants to maintain production with time. In addition, removing NH_4^+ from the nutrient solution just after set of the 3rd truss could diminish the possible toxic effect of NH_4^+ on plant growth.

Fruit quality was increased by salinity and NH_4^+ treatments (Tab. II, Figs. 2 and 3). However, treatments that did not

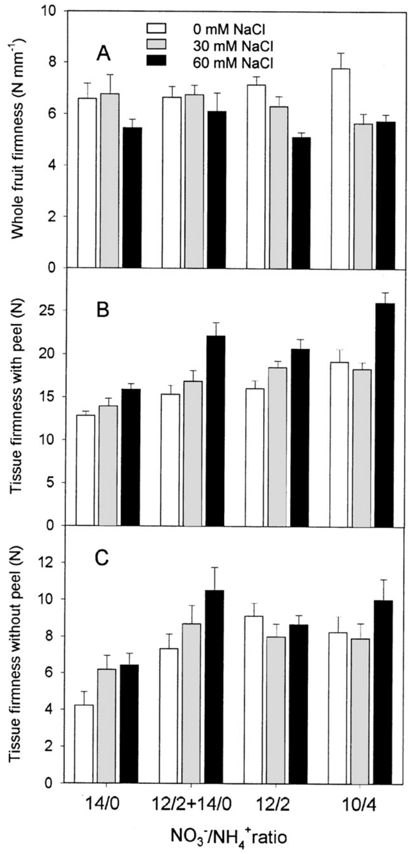

Figure 3. Whole fruit and tissue (with or without peel) firmness of tomatoes as affected by salinity (0, 30 and 60 mM NaCl) and different NO_3^-/NH_4^+ mM ratios (14/0, 12/2+14/0, 12/2 and 10/4). Values are means of eight replicates (± SE).

decrease total yield (control + 12/2+14/0 or 30 mM NaCl + 14/0) did not increase fruit quality. Thus, the increase in fruit quality was associated with a decrease in yield. The use of moderately saline water (3–6 $dS \cdot m^{-1}$) for irrigation has been recommended to improve fruit quality [17]. However, special care must be taken when using saline water in a commercial crop. Above an electrical conductivity of 2.5 $dS \cdot m^{-1}$, a 10% yield reduction per additional $dS \cdot m^{-1}$ is expected [21]. In modern hybrids, TSS increases at a rate of 10.5% per additional $dS \cdot m^{-1}$ and thereby productivity in terms of quality and quantity would remain unaltered, at least between 2.5 and 8–9 $dS \cdot m^{-1}$ [4].

In this experiment salinity increased citric acid in tomatoes of the second truss, whereas NH_4^+ significantly increased citric acid in tomatoes from the fifth truss. Salinity and NH_4^+ tended to increase glucose and fructose. However, the greatest difference regarding sugars and organic acids was observed when comparing tomatoes from the second and fifth trusses. Sugar and acid contents and their ratio are important for sweetness, sourness and flavor [25]. Fructose and citric acid are more important to sweetness and sourness than glucose and malic acid, respectively [12].

Color (expressed in values of “a”) was used as a physiological measurement of the actual developmental age of fruit because there is a high correlation between the development of lycopene and the maturity of the fruit [28]. In our experiment, there were no color differences between treatments. It was important to ensure that tomatoes used for physical and chemical quality determinations were at the same developmental age and, thus, that changes in chemical constituents were only due to exposure to the different treatments.

Firmness measurements are important for determining the shelf life of fruits. In our experiment, physical attributes of fresh fruit were affected by salt stress and the NO_3^-/NH_4^+ mM ratio. Salinity had contradictory effects on firmness when it was determined on whole fruit or fruit tissue, with or without peel. It seems to have a negative effect on fruit resistance to deformation (whole fruit firmness), decreasing it at intermediate and high salinity for the NH_4^+ treatment (12/2 and 10/4), but only at high salinity for the NO_3^- treatment (14/0). However, tissue firmness with peel increased with salinity for all N-treatments. Petersen et al. [19] found that the pericarp of tomatoes grown at increased salinity (7.0 $dS \cdot m^{-1}$) consisted of smaller cells with thicker walls. This could explain the salinity-induced increase in tissue firmness in our experiment. Petersen et al. [19] did not find an effect of increasing salinity on firmness when it was measured on fruit without peel. In our study, tissue firmness without peel increased with salinity, but there was no clear effect for ammonium-fed tomatoes. Although NH_4^+ did not significantly affect whole fruit firmness, a significant increase in tissue firmness was observed due to increasing NH_4^+ in the nutrient solution.

Fruit Ca^{2+} concentration was decreased by salinity or NH_4^+, the negative effect of NH_4^+ being higher than the effect of salinity. Salinity decreases uptake of Ca^{2+} by roots and increases the resistance to transport inside the fruit [14]. Also, a strong antagonism between NH_4^+ and Ca^{2+} nutrition has been observed in tomato plants [13]. One of the most important physiological disorders related to tomato quality is blossom-end rot. It has been associated with a local calcium deficiency induced by salinity, high temperature, or low humidity [2, 14]. However, although calcium concentration in fruit decreased with salinity and NH_4^+, the incidence of blossom-end rot in this experiment was minimal, possibly because it was carried out in the fall to winter season, with low temperatures and high humidity.

Moderate salinity (30 mM NaCl) did not reduce tomato yield when NO_3^- was the only N source throughout. Application of NH_4^+ during early growth stages of tomato plants led to maintenance of tomato fruit size during later stages of growth and tended to increase fruit quality. Higher yields were obtained when plants were fed with NO_3^- as the only nitrogen source during fruit development. Although salinity and NH_4^+ significantly increased fruit quality, this effect was associated with a decrease in yield.

Acknowledgements: The authors wish to thank Nieves Fernández for helping with sample analysis and Dr. David Walker for correction of the English in this manuscript. This work was funded by CICYT (PETRI)-Spain (project No. 95-0174-OP).

Table III. Effects of salinity and NO_3^-/NH_4^+ ratio on ion composition of tomato fruit collected from 2nd truss.

		Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
		meq/100 g				
MAIN EFFECT						
Salinity level	0	13.4a	2.8a	73.7	5.7a	7.6
(mM NaCl)	30	20.9b	5.6b	75.0	5.8a	7.9
	60	25.4c	8.8c	71.1	3.7b	7.4
		***	***	n.s.	***	n.s.
Nitrogen	14/0	15.5a	5.3	74.8ab	7.2a	8.4a
(NO_3/NH_4 ratio)	12/2+14/0	17.6a	5.2	77.5b	6.0b	7.9a
	12/2	21.3b	6.2	71.0ab	3.9c	7.6ab
	10/4	25.6c	6.4	69.0a	3.4c	6.7b
		***	n.s.	**	***	***
SALINITY × NITROGEN						
NO_3/NH_4 ratio	sal					
14/0	0	10.6a	2.7	74.5	7.4de	8.4
	30	14.8ab	4.7	79.2	8.5f	9.0
	60	19.6bc	8.6	70.6	5.6bcde	8.0
12/2+14/0	0	10.4a	2.6	83.6	6.6cde	8.0
	30	19.6bc	4.9	78.4	7.4e	8.1
	60	22.7cd	8.1	70.6	3.9ab	7.5
12/2	0	14.1ab	3.0	66.7	4.1abc	7.2
	30	19.8bc	5.7	72.5	4.2abc	7.9
	60	30.1e	9.9	74.0	3.5ab	7.7
10/4	0	18.2bc	2.9	68.8	4.8abcd	7.0
	30	29.9de	6.9	69.3	3.2ab	6.7
	60	27.9de	8.7	69.1	2.5a	6.5
		**	n.s.	n.s.	**	n.s.

*, ** and ***, significant differences between means at the 5, 1 and 0.1% levels of probability, n.s., non-significant at $P = 5\%$. Different letters in the same column indicate significant differences between salinity levels, nitrogen treatment and salinity × nitrogen, respectively, at the 5% level of probability.

REFERENCES

[1] Adams P., Effects of increasing the salinity of the nutrient solution with major nutrients or sodium chloride on the yield, quality and composition of tomatoes grown in rockwool, J. Hortic. Sci. 66 (1991) 201–207.

[2] Adams P., Ho L.C., The susceptibility of modern tomato cultivars to blossom-end rot in relation to salinity, J. Hortic. Sci. 67 (1992) 827–839.

[3] Ali I.A., Kafkafi U., Sugimoto Y., Inanaga S., Response of sand-grown tomato supplied with varying ratios of nitrate/ammonium to constant and variable root temperatures, J. Plant Nutr. 17 (1994) 2001–2024.

[4] Cuartero J., Fernández-Muñóz R., Tomato and salinity, Sci. Hortic. 78 (1999) 83–125.

[5] Cuartero J., Soria T., Productividad de tomates cultivados en condiciones salinas, Actas Hortic. 16 (1997) 214–221.

[6] Cuartero J., Baena J., Soria T., Fernández-Muñoz R., Evolución de la dureza del fruto del tomate, como un componente de la calidad, en cultivares de larga duración y normales cultivados en 5 concentraciones salinas, Actas Hortic. 13 (1996) 59–65.

[7] Ehret D.L., Ho L.C., The effects of salinity on dry matter partitioning and fruit growth in tomatoes grown in nutrient film culture, J. Hortic. Sci. 61 (1986) 361–367.

[8] Evans R.D., Bloom A.J., Sukrapanna S.S. Ehleringer J.R., Nitrogen isotope composition of tomato (*Lycopersicon esculentum* Mill. cv. T-5) grown under ammonium or nitrate nutrition, Plant Cell Environ. 19 (1996) 1317–1323.

[9] Feng J., Barker A.V., Ethylene evolution and ammonium accumulation by tomato plants under water and salinity stresses, J. Plant Nutr. 15 (1992) 2471–2490.

[10] Ganmore-Neumann R., Kafkafi U., Root temperature and percentage NO_3^-/NH_4^+ effect on tomato plant development: I Morphology and growth, Agron. J. 72 (1980) 758–761.

[11] Gao Z.F., Sagi M., Lips S.H., Carbohydrate metabolism in leaves and assimilate partitioning in fruits of tomato (*Lycopersicon esculentum*), Plant Sci. 135 (1998) 149–159.

[12] Grierson D., Kader A.A., Fruit ripening and quality, in: Atherton J.G., Rudich J. (Eds.), The tomato crop. A scientific base for improvement, Chapman & Hall, London, 1986, pp. 241–280.

[13] Hartman P., Harry L., Mills A., Benton J. Jr., The influence of nitrate:ammonium ratios on growth, fruit development, and element concentration in "Floradel" tomato plants, J. Am. Soc. Hortic. Sci. 111 (1986) 487–490.

[14] Ho L.C., Brown R.B.M., Andrews J., Adams P., Uptake and transport of calcium and the possible causes of blossom-end rot in tomato, J. Exp. Bot. 44 (1993) 509–518.

[15] Martínez V., Núñez J.M., Ortiz A., Cerdá A., Changes in amino acid and organic acid composition in tomato and cucumber plants in relation to salinity and nitrogen nutrition, J. Plant Nutr. 17 (1994) 1359–1368.

[16] Mitchell J.P., Shennan C., Grattan S.R., May D.M., Tomato fruit quality under water deficit and salinity, J. Am. Soc. Hortic. Sci. 116 (1991) 215–221.

[17] Mizrahi Y., Taleisnik E., Kagan-Zur V., Zohar Y., Offenbach R., Matan E., Golan R., A saline irrigation regime for improving tomato fruit quality without reducing yield, J. Am. Soc. Hortic. Sci. 113 (1988) 202–205.

[18] Ortiz A., Martínez V., Cerdá A., Effects of osmotic shock and calcium on growth and solute composition of *Phaseolus vulgaris* plants, Physiol. Plant. 91 (1994) 468–476.

[19] Petersen, K.K., Willumsen J., Kaack K., Composition and taste of tomatoes as affected by increased salinity and different salinity sources, J. Hortic. Sci. Biotech. 73 (1998) 205–215.

[20] Pill W.G., Lambeth V.N., Effects of NH_4^+ and NO_3^- nutrition with and without pH adjustment on tomato growth, ion composition, and water relations, J. Am. Soc. Hortic. Sci. 102 (1977) 78–81.

[21] Saranga Y., Zamir D., Marani A., Rudich J., Breeding tomatoes for salt tolerance: field evaluation of *Lycopersicon* germplasm for yield and dry-matter production, J. Am. Soc. Hortic. Sci. 116 (1991) 1067–1071.

[22] Scholberg J.M.S., Locascio S.J., Growth response of snap bean and tomato as affected by salinity and irrigation method, HortScience 34 (1999) 259–264.

[23] Sharaf A.R., Hobson G.E., Effect of salinity on the yield and quality of normal and non-ripening mutant tomatoes, Acta Hortic. 190 (1986) 175–181.

[24] Smith M.A.L., Spomer L.A., Shibli R.A., Knight S.L., Effects of NaCl salinity on miniature dwarf tomato micro-tom 2. Shoot and root growth responses, fruit production, and osmotic adjustment, J. Plant Nutr. 15 (1992) 2329–2341.

[25] Stevens A.M., Kader A.A., Albright-Holton M., Intercultivar variations in composition of locular and pericarp portion of fresh market tomatoes, J. Am. Soc. Hortic. Sci. 102 (1977) 689–692.

[26] Ullah S.M., Gerzabek M.H., Sonja G., Effect of seawater and soil salinity on ion uptake, yield and quality of tomato (fruit), Bodenkultur 45 (1994) 227–237.

[27] Van Ieperen W., Effect of different day and night salinity levels on vegetative growth, yield and quality of tomato, J. Hortic. Sci. 71 (1996) 99–111.

[28] Young T.E., Juvik J.A., Sullivan J.G., Accumulation of the components of total solids in ripening fruits of tomato, J. Am. Soc. Hortic. Sci. 118 (1993) 286–292.