(Aus dem Bereich Lebenswissenschaften des Österreichischen Forschungszentrums Seibersdorf Ges. m. b. H.)

Effect of seawater and soil salinity on ion uptake, yield and quality of tomato (fruit)

By S. M. ULLAH, M. H. GERZABEK and G. SOJA[1]

(With 2 figures)

Summary

In a pot experiment the influence of irrigation with artificial seawater and of soil salinity on tomato plants and fruit quality was investigated. The sum of the salt concentrations in irrigation water was 0, 30, 60 and 100 mM (seawater salinity: $NaCl : MgCl_2 : MgSO_4 = 20 : 1 : 1$; soil salinity: $Na_2SO_4 : MgCl_2 = 4 : 1$ on molar basis).

Dry matter production of tomato plants was significantly increased by soil salinity but not by seawater salinity. Tomato fruit production was adversely affected only by high salt concentrations. Salt stress increased the uptake of Na, Mg and chloride ions in tomato plants. Sodium reduced the uptake of potassium due to ion antagonism. Sulphate uptake in tomato plants was increased by salt application only under soil salinity. Phosphate ion uptake was significantly reduced by salt stress. Chloride ions did not antagonize the uptake of nitrate in tomato plants. Absorption of calcium remained unaffected by salt stress. Iron uptake decreased significantly only under seawater salinity.

Glucose, fructose, ascorbic acid and citric acid contents were significantly enhanced in tomato fruits by salinity; synthesis of sucrose and malic acid remained unaffected.

The increases in the concentrations of sodium, chloride and monosaccharides might have contributed to osmotic adjustment in tomato plants. Salinity increased the contents of sugars and acids (ascorbic and citric acid) of the tomato fruits and thus improved the fruit quality.

Key-words: tomato, fruit quality, osmotic adjustment, ion balance, salinity.

Einfluß von Seewasser und Bodenversalzung auf Ionenaufnahme, Ertrag und Qualität von Tomatenfrüchten

Zusammenfassung

In einem Gefäßversuch wurde der Einfluß der Bewässerung mit Salzlösungen auf Tomatenpflanzen und deren Fruchtqualität untersucht. Die Summe der

[1] corresponding author

Salzkonzentrationen im Gießwasser betrug 0, 30, 60 und 100 mM („Seewasserversalzung“: NaCl : $MgCl_2$: $MgSO_4$ = 20 : 1 : 1; „Bodenversalzung“: Na_2SO_4 : $MgCl_2$ = 4 : 1 auf molarer Basis).

Die Trockensubstanzproduktion der Tomatenpflanzen stieg signifikant in den Varianten „Bodenversalzung“, aber nicht bei „Seewasserversalzung“. Ein negativer Einfluß auf die Fruchtproduktion wurde nur bei sehr hohen Salzkonzentrationen beobachtet. Salzstreß erhöhte die Na-, Mg- und Cl-Ionenaufnahme der Tomatenpflanzen, wobei der Anstieg der Na-Gehalte aufgrund von Ionenkonkurrenz mit einer Abnahme der Kaliumgehalte verbunden war. Die Sulfataufnahme erhöhte sich nur bei Bodenversalzung, die Phosphatgehalte wurden durch Salzstreß in jedem Fall signifikant vermindert. Ionenkonkurrenz zwischen Cl^- und NO_3^- wurde nicht beobachtet, ebenso blieb die Calciumaufnahme von den Salzbehandlungen unbeeinflußt. Die Eisenaufnahme ging bei den Seewasservarianten signifikant zurück.

Die Glukose-, Fruktose-, Ascorbin- und Zitronensäuregehalte wurden durch die Salzapplikationen erhöht, die Synthese von Disacchariden und Äpfelsäure blieb unbeeinflußt.

Der Anstieg der Konzentrationen von Natrium, Chlorid und den Monosacchariden gaben den Tomatenpflanzen die Möglichkeit zur osmotischen Anpassung. Die Erhöhung der Zucker-, Ascorbinsäure- und Zitronensäuregehalte der Tomaten durch Salzstreß führte zu einer verbesserten Fruchtqualität.

Schlüsselworte: Fruchtqualität, Ionenbilanz, osmotische Anpassung, Tomaten, Versalzung.

1. Introduction

Salt stress reduces the free energy of water in soils available to plants (Flowers and Yeo 1986, Loos and Widmoser 1986) and results in negative water potential in soils (Wood and Gaff 1989, Ullah et al. 1989, 1993). This drop in water potential is accompanied by specific ion toxicities, deficiencies, retardation of water uptake and nutritional imbalances in plants (Greenway and Munns 1980, Bernstein 1963, Cusido et al. 1987, Plaut and Grieve 1988, Pessarakli et al. 1989, Matsumoto and Chung 1990, He and Cramer 1992, Ullah et al. 1993, McCue and Hanson 1992), which affect enzymatic and physiological functions reducing growth and yield of crops (Abdul-Kadir and Paulsen 1982, Holder and Christensen 1988, Adams 1988, Pessarakli et al. 1989, Al-Rawahy et al. 1990, Ullah et al. 1989, 1993). Therefore the water potential of the symplast must be adjusted, if the plant is not to be desiccated (Flowers and Yeo 1986). In halophytes such adjustment usually occurs by absorbing inorganic ions (Hsiao et al. 1976, Flowers et al. 1977, McCree 1986) from the salts as osmotica, while in glycophytes the exclusion or export of salts to the exterior and the generation of sufficient organic molecules as osmotica help maintaining the turgor (McCue and Hanson 1992). The mechanism of salt tolerance in halophytes is related to the control of the internal osmotic potential by raising the levels of Na^+ and Cl^- concentrations, while protecting the cells against their toxic effects (Garcia-Reina et al. 1988).

Tomato is a moderately salt tolerant crop and is being widely cultivated even in areas with salt influenced soils or irrigation water. Ion imbalances, shift in enzymatic reactions and biological processes caused by salinity may also affect the quality and flavour of the tomato fruits.

It was the objective of this investigation to determine the effect of salt stress on yield of tomato fruits, dry matter production, ion uptake, osmotic adjustment and quality of fruits. In this experiment, plants were stressed by the addition of salts corresponding to simulated seawater and soil salinity (coastal saline soil). The combination of different salts was preferred to the addition of single salts because this can be considered to be more representative for a generalized plant response to salinity.

2. Materials and Methods

Plastic pots were filled with 8 kg air-dried soil of Großenzersdorf, Austria, which was screened through a 2 mm sieve and had the following characteristics: sand 34.8 %, silt 46.6 % and clay 18.6 %, pH 7.53, organic matter 2.00 %, $CaCO_3$ 23 %, water-holding capacity 45 %, CEC 18.5 meq/100 g soil, N 0.122 %, P 0.049 %, Ca 9.18 %, Mg 2.43 %, Fe 1.93 %, K 0.19 % and Na 8.5 mg/100 g soil. Water soluble anions and cations were measured in the saturation water extract: 488 mg HCO_3^-/l, 31 mg NO_3^-/l, 390 mg Cl^-/l, 0.63 mg PO_4^{3-}/l, 315 mg Ca^{2+}/l, 23.3 mg Mg^{2+}/l, 22.6 mg K^+/l, 22.5 mg Na^+/l, 7.2 mg NH_4^+/l. Two tomato plants, two weeks old and of uniform size, were transplanted to each pot. The number of plants was thinned to one after one week of transplantation. The pots were arranged in a completely randomized design in the open field with six replications for each treatment.

The tomato plants (cv. Lukullus) were allowed to grow in the pots for two weeks without salt treatments. During this period, pots were irrigated with deionized water. Then they were exposed to constant levels of salt stress equivalent to seawater and soil salinity stress levels. This was accomplished by irrigation with salt solutions (treatments: 0, 30, 60 and 100 mM salt concentration; total amount of salts applied per pot: 0, 0.6, 1.2 and 2.0 M at constant rate in the period June–August). Artificial seawater and soil salinities were simulated with a combination of salts (seawater salinity: $NaCl : MgCl_2 : MgSO_4 = 20 : 1 : 1$; soil salinity: $Na_2SO_4 : MgCl_2 = 4 : 1$). After harvest of the ripe tomatoes, fresh weight was recorded and visual quality and physical damage of tomatoes were determined according to the rating scale of Grierson and Kader (1986). Three tomatoes from each pot were cut into pieces for application of the rating scale for internal tissue damage due to bruising, the rest of the fruits was frozen for other investigations.

The total fresh weight of the tomatoes was calculated by summing up the fresh weight of all the harvests.

Three frozen tomatoes from each pot were minced separately by an electric mixer and extracted with water (60 °C). In the extract (with carrez solutions), the contents of glucose, fructose, sucrose, citric acid and L-malic acid were analyzed by enzymatic methods (Boehringer-Mannheim 1989). For the assay of ascorbic acid, fruit samples were well minced with an electric mixer and homogenized in meta phosphoric acid (15 % w/v). The pH of the mixture was adjusted to 3.7 with KOH and ascorbic acid was determined by enzymatic methods (Boehringer-Mannheim 1989).

After the last fruit harvest, tomato plants were completely harvested, dried at 70 °C for four days, weighed and finely ground. The powdered samples were used for various analyses. Chloride, nitrate, sulphate and phosphate were determined in the tomato plants by ion chromatography (Dionex Model 2010 i) after extraction of the powdered samples with deionized distilled water in a shaking hot water-bath (80 °C) for 10 min. The extraction procedure was repeated twice and the decanted supernatants were bulked and filtered (Wood and GAFF 1989). Frozen tomato fruits were freeze-dried, again dried in an oven at 60 °C and powdered.

Sodium, potassium, calcium, magnesium, phosphorus and iron were determined by plasma emission spectrometry (Perkin Elmer Plasma II) after wet digestion of both fruit and shoot samples in a $HNO_3 : HClO_4$ (5 : 1) mixture. Finally the results were statistically analysed with the Waller-Duncan K-ratio t-test (SAS-software). Mean values in columns followed by the same letter are not significantly different.

3. Results and Discussion

The types of salts influenced the growth of tomato plants. Soil salinity had a more positive impact on dry matter production than seawater salinity (fig. 1). The highest dry matter production was observed at a salt concentration of 100 mM soil salinity (13.5 g DM/plant, 125 % of the control). This higher production of dry matter was probably due to the uptake of sulphate, which was nearly doubled at 60 mM and 100 mM soil salinity, while sulphate ions taken up by the control plants might be involved in balancing Ca in the vacuoles.

ADAMS (1988) also reported that growth of tomato plants was stimulated by increasing salinity to 4 to 5 mS/cm due to application of sodium chloride. However, many investigators (ATTENBURROW and WALLER 1980, KAFKAFI et al. 1982, PESSARAKLI and TUCKER 1988, AL-RAWAHY et al. 1990) observed a significant decline in dry matter yield of tomato plants by increasing salinity. Variations in dry matter production were also dependent on salt types (RYAN et al. 1975) and among the soluble salts. NaCl is the most detrimental to plant growth and nutrient uptake (AL-RAWAHY et al. 1990). In their experiments, seawater containing high amounts of NaCl produced a reduced amount of dry matter compared with soil salinity.

Low levels of salinity hardly affected tomato fruit yield (fig. 2). No decline in yield compared with the control treatment was observed at 30 mM salts. However, fruit yield was significantly affected by 100 mM salt stress, where a yield reduction of 21 % and 27% of the control treatment was recorded under seawater salinity (SWS) and soil salinity (SS), respectively. Such reduction in yields might have been caused by physiological disorders, impaired biochem-

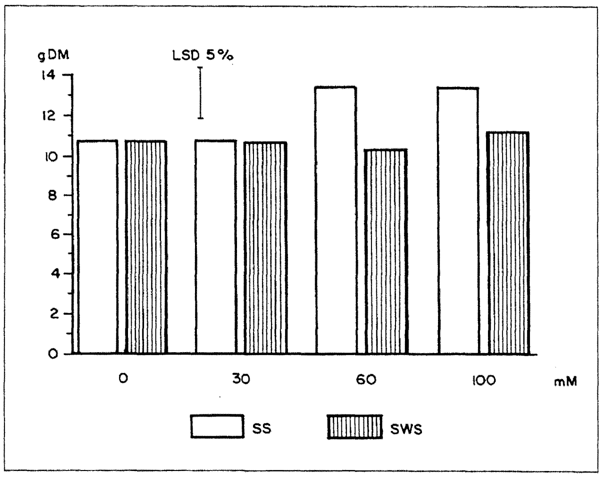
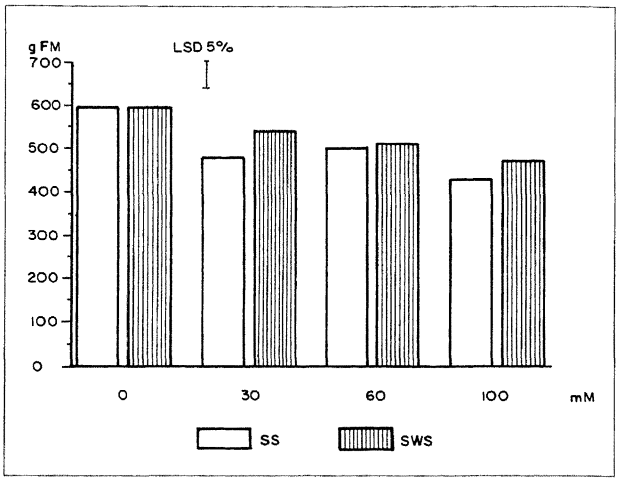


Fig. 1: Influence of salt stress on dry matter production of tomato plants (stems and leaves) (SS = soil salinity; SWS = seawater salinity).

Fig. 2: Influence of salt stress on fresh matter production of tomato fruits (SS = soil salinity; SWS = seawater salinity)



ical, physiological and enzymatic processes associated with salt stress (BERNSTEIN 1963, ULLAH et al. 1989, 1993, MCCUE and HANSON 1992). Reduction in tomato yields with increasing salt concentrations was also reported by KAFKAFI et al. (1982) and STROGONOV (1964).

Cations were determined both in tomato plants (shoots) and fruits. Anions were estimated only in tomato plants. Salt stress had a significant impact on Na-uptake by tomato plants as well as its transportation to fruits (table 1). Sodium concentration increased significantly with the increase in salt concentrations both in fruits and tomato plants (table 1). The highest amount of sodium was found at 100 mM salts (1.43 % at SWS and 1.62 % at SS in tomato plants; 0.17 % Na at SWS and 0.19 % Na at SS in fruits). Compared with the control treatment, a more than 14 and 16 fold increase in Na content was observed in tomato plants (shoots) at 100 mM salts of seawater and soil salinity, respectively; while it was about 6 times higher in fruits compared with the control plants both in case of SWS and SS at 100 mM salt stress. Tomato fruits had much lower contents of Na than stem and leaf material (table 1).

Table 1

Effect of seawater salinity (SWS) and soil salinity (SS) on Na, K, Ca and Mg concentrations (%) in tomato shoots and fruits

treatment	mM salts	% Na shoot	% Na fruit	% K shoot	% K fruit	% Ca shoot	% Ca fruit	% Mg shoot	% Mg fruit
control	0	0.10 e	0.03 d	1.86 a	4.44 a	5.27 ab	0.23 a	0.90 b	0.16 a
SWS	30	0.57 d	0.08 c	1.41 b	4.27 ab	5.84 a	0.19 ab	0.97 ab	0.16 a
SWS	60	0.92 c	0.13 b	1.12 c	4.27 ab	6.02 a	0.23 a	1.04 a	0.17 a
SWS	100	1.43 b	0.17 a	0.92 c	3.85 bc	5.13 ab	0.22 ab	0.97 ab	0.15 a
SS	30	0.82 c	0.09 c	1.10 c	4.06 abc	5.36 ab	0.19 ab	0.89 b	0.16 a
SS	60	1.44 b	0.14 b	0.89 c	4.20 ab	5.28 ab	0.18 b	0.96 ab	0.16 a
SS	100	1.62 a	0.19 a	0.88 c	3.64c	4.70 b	0.20 ab	0.91 b	0.16 a

Salinity had an adverse impact on K-uptake by tomato plants. Its concentration declined significantly compared with the control treatment with increasing salt stress, the lowest amounts (0.92 % K at SWS and 0.88 % K at SS) being measured at 100 mM salt stress. However, tomato fruits accumulated more K (up to four times) than tomato plants (table 1). There was no difference in potassium contents of fruits between the control and salt treatments except at 100 mM salts under both seawater and soil salinity (table 1). Potassium concentrations were reduced by 50 and 63 % in tomato plants compared with the control treatment at 100 mM seawater and soil salinity, respectively, while in the fruits, the reductions were only 13 and 18 % under the same seawater and soil salinity. K/Na ratio was also diminished with increasing salt concentrations (table 2). This ratio was much higher in tomato fruits than in tomato plants. A minimum of 0.65 under seawater salinity and 0.54 under soil salinity was observed in tomato plants, while the corresponding values in tomato fruits were 22.7 and 19.2 (table 2).

Table 2

Effect of seawater salinity (SWS) and soil salinity (SS) on P and Fe concentrations and on K/Na, Na/Ca and Ca/Mg ratios in tomato shoots and fruits

treatment	mM salts	% P shoot	% P fruit	Fe (ppm) shoot	Fe (ppm) fruit	K/Na shoot	K/Na fruit	Na/Ca shoot	Na/Ca fruit	Ca/Mg shoot	Ca/Mg fruit
control	0	0.35a	0.44a	957a	49a	18.60	148.00	0.02	0.13	5.86	1.35
SWS	30	0.34a	0.38bc	739ab	42bc	2.47	53.38	0.10	0.42	6.02	1.19
SWS	60	0.32ab	0.38bc	672b	43b	1.22	32.85	0.15	0.57	5.79	1.35
SWS	100	0.26c	0.36bcd	648b	44ab	0.64	22.65	0.28	0.77	5.29	1.47
SS	30	0.27bc	0.40ab	766ab	45ab	1.34	45.11	0.15	0.47	6.02	1.19
SS	60	0.26c	0.35cd	785ab	37c	0.62	30.00	0.27	0.78	5.50	1.13
SS	100	0.25c	0.33d	881ab	29d	0.54	19.16	0.34	0.95	5.16	1.25

Magnesium concentrations either remained constant or were enhanced by salt applications compared with the control treatment (table 1). The higher concentrations of Mg in some of the salt treated plants were due to its presence in the simulated salt solutions. In tomato fruits, no difference in Mg content between the control and salt treated plants was observed (table 1). Tomato shoots had much higher contents of magnesium (about 6.5 fold) than fruits (table 1). It varied from 0.89 % to 1.04 % in tomato plants, while in tomato fruits, it ranged from 0.15 % to 0.17 %.

Calcium uptake by tomato plants was not adversely affected by salt stress except under 100 mM soil salinity (table 1). Like magnesium, calcium contents were also much higher in tomato plants (shoots) than in fruits (up to 31 folds). Ca/Mg ratio did not change with salt concentrations. The highest ratio was observed in tomato shoots (table 2). Maintenance of Ca contents in the salt treated plants at the same level as the control treatment helped in regulating ion transport and membrane permeability and hence normal growth of tomato plants. However, Na/Ca ratio increased with salinity both in tomato plants and fruits (table 2). This ratio was higher under soil salinity than seawater salinity. The highest value of Na/Ca ratio was observed in tomato fruits (0.95; about 3 times higher than in plants).

Iron concentration in tomato plants was significantly reduced by seawater salinity at 60 and 100 mM salts, while soil salinity had no adverse effect on iron uptake by tomato plants compared with the control treatment (table 2). Salinity reduced the accumulation of iron in tomato fruits. Tomato plants had higher contents of iron (up to 30 folds) than tomato fruits (table 2). Soil salinity exerted pronounced adverse impact on phosphorus absorption by tomato plants compared with the control treatments; on the other hand, SWS did not have any effect on phosphorus uptake by tomato plants except at 100 mM salt. The minimum phosphorus content (0.25 %) was measured at 100 mM soil salinity. Tomato fruits accumulated more P than the vegetative plant parts. Phosphorus concentration decreased due to salt treatments (table 2).

Salinity effects on ion uptake and accumulation are reported not only from tomato plants and fruits, but also from a number of other species, such as sugar beet, beans, wheat, barley, cotton, rice, grass and Brassica sp. (PALFI 1963, AYOUB 1974, FROTA and TUCKER 1978, TORRES and BINGHAM 1973, RATHERT 1983, FLOWERS and YEO 1986, FRANCOIS et al. 1988, CRAMER et al. 1991, HE and CRAMER 1992). Salinity increased the concentrations of Na in tomato plants as well as in fruits. High uptake of Na in tomato plants occurred in response to the establishment of the equilibrium with the potential of the soil solutions necessary for normal metabolic processes without inducing toxic effects to the cell.

Concentration of K declined due to an antagonism with Na. This antagonism could be the result of direct competition between K and Na at the site of ion uptake at plasmalemma (EPSTEIN and RAINS, 1987, HE and CRAMER 1992). Sodium could also enhance the efflux of K into the growth medium (CRAMER et al. 1985, HAJJI and GRIGNON 1985), possibly due to membrane integrity (HE and CRAMER 1992). A positive relation existed between Mg and salt concentrations. The increase in Mg concentrations in tomato plants was due to its presence in the artificial seawater and soil salinity. However, its presence in the salt solutions did not influence its accumulation in the tomato fruits. Probably its transport in excess from the shoots to the fruit was restricted. Calcium concentrations in tomato plants were not affected by salt stress, although high concentration of Na in the external medium has been reported to suppress its content in the plant material due to its antagonism with sodium (GREENWAY and MUNNS 1980, RATHERT 1983, HE and CRAMER 1992), sometimes to a degree that causes calcium deficiencies (MAAS and GRIEVE 1987, HE and CRAMER 1992) and accelerates passive accumulation of Na ions. Calcium concentrations in the tomato plants as they have been observed in the control treatment are considered to be very important in regulating ion transport and membrane permeability (GRATTAN and MAAS 1988). The essentially missing antagonistic influence of Na on Ca uptake in tomato plants showed a tolerance of these plants to salt stress.

Phosphate concentrations declined with increasing salt concentrations in tomato plants. Probably both chloride and sulphate ions in the simulated salt solutions depressed the uptake of PO_4^{3-} by tomato plants and its accumulation in fruits.

Salt stress influenced the anion concentrations in tomato plants. Like sodium, chloride contents in tomato plants were significantly enhanced by salt stress compared with the control treatment (table 3). Chloride concentrations under seawater salinity were higher than under the corresponding soil salinity levels because of higher concentrations in the irrigation solution. Contents of chloride increased in tomato plants in response to the maintenance of internal osmotic potential and ion balance while protecting the cells from its toxic effects (GARCIA-REINA et al. 1988).

Sulphate concentration in tomato plants increased with increasing salt concentrations under soil salinity, but there was no difference in SO_4^{2-} contents between the seawater salinity and control treatments (table 3). Soil salinity enhanced SO_4^{2-} contents significantly especially at 60 and 100 mM salt compared with control plants (table 3). Sulphate concentrations varied from 2.18 % under

Table 3

Effect of seawater salinity (SWS) and soil salinity (SS) on Cl^-, NO_3^-, SO_4^{2-} and PO_4^{3-} ion concentrations in tomato shoots

treatment	mM salts	% Cl^-	% NO_3^-	% SO_4^{2-}	% PO_4^{3-}
control	0	1.06 d	0.22 a	2.18 b	0.469 a
SWS	30	2.47 bc	0.21 a	2.38 b	0.390 ab
SWS	60	2.81 bc	0.21 a	2.32 b	0.259 c
SWS	100	4.38 a	0.19 a	2.48 b	0.231 c
SS	30	2.31 c	0.21 a	2.72 b	0.325 bc
SS	60	2.78 bc	0.20 a	4.34 a	0.249 c
SS	100	2.98 b	0.19 a	4.05 a	0.263 c

control conditions to 4.34 % under soil salinity. Sulphate uptake by tomato plants in higher amounts under soil salinity compared with the seawater salinity was due to the presence of this ion in the irrigation solution. Phosphate concentrations in plants declined significantly by salt treatments (table 3). Probably chloride and sulphate ions reduced the uptake of phosphate ions in tomato plants. Nitrate uptake in tomato plants was not antagonized by chloride ions (table 3). No difference in nitrate concentrations between the control and salt treated plants was observed. LANGDALE and THOMAS (1971) also reported that soil salinity did not inhibit the uptake of nitrogen by highly salt-tolerant bermudagrass. HERNANDO et al. (1967) found that nitrogen absorption by moderately salt-tolerant tomato plants was not affected by salinity. However, many investigators (TORRES and BINGHAM 1973, LUQUE and BINGHAM 1981, PALFI 1963, PESSARAKLI and TUCKER 1985, ULLAH et al. 1989, 1993) reported that nitrogen uptake was reduced by the application of salts in a number of plant species. Nitrogen and phosphorus uptake by a moderately salt-tolerant wheat crop were retarded under high NaCl and Na_2SO_4 salinity in the root medium (MAHAJAN and SONAR 1980).

Contents of glucose, fructose, ascorbic acid and citric acid were significantly increased by the salt stress (table 4). This increase was considerably enhanced at 100 mM salts compared with other treatments.

Table 4

Effect of seawater salinity (SWS) and soil salinity (SS) on glucose, fructose, sucrose, citric acid, ascorbic acid and malic acid contents (%) in tomato fruits

treatment	mM salts	% glucose	% fructose	% sucrose	% citric acid	% ascorbic acid	% malic acid
control	0	1.32 c	1.95 b	0.18 a	0.41 c	0.025 d	0.087 a
SWS	30	1.73 bc	2.17 b	0.09 b	0.51 ab	0.035 c	0.096 a
SWS	60	2.57 ab	3.07 ab	0.13 ab	0.51 ab	0.040 b	0.080 a
SWS	100	3.16 a	3.91 a	0.14 ab	0.56 ab	0.050 a	0.097 a
SS	30	1.76 bc	2.20 b	0.10 b	0.48 ab	0.032 c	0.094 a
SS	60	2.18 abc	2.56 ab	0.10 b	0.55 ab	0.038 b	0.104 a
SS	100	2.56 ab	2.95 ab	0.12 ab	0.58 a	0.048 a	0.102 a

Glucose concentrations were increased up to 139 % and fructose up to 101 % above the control treatment. These organic molecules act as osmotica and play an important role in osmotic adjustment in the plants (GREENWAY and MUNNS 1980, FLOWERS et al. 1977, MCCREE 1986). Many higher plant species synthesize and store compatible osmolytes (proteins, amino acids, prolines, glycine, betain etc.) in salt stressed plants and contribute to osmotic adjustment (GREENWAY and MUNNS 1980, WYN JONES and STOREY 1981, ROBINSON and JONES 1986, MATOH et al. 1987, McCUE and HANSON 1992, ULLAH et al. 1993). However, sucrose contents in tomato fruits either remained constant or decreased due to salinity compared with the control treatment (table 4).

Citric acid as well as ascorbic acid in tomatoes were significantly enhanced in response to salt stress compared with the control conditions (table 4). The highest concentration of citric acid was observed at 100 mM soil salinity, while the highest amount of ascorbic acid (0.05 %) was measured at 100 mM seawater salinity (table 4). ADAMS (1988) reported that increasing the levels of NaCl always improved fruit quality, increased dry matter, sugar contents and acidity of the fruit juices. According to CUSIDO et al. (1987), retardation of potassium contents in plants due to salinity increased amino acids, specially aspartic acid, glutamic acid and proline contents. Salinity did not exert any significant influence on malic acid production and its accumulation in tomato plants.

Ripeness classes of tomatoes were determined according to GRIERSON and KADER (1986). The tomatoes were red over 90 % classified as red and scored 6 of Grierson and Kader's table 6.5 in all treatments. No difference was found between the control and salt treatments.

With regard to internal tissue damage due to bruising, no degree of severity and no visible internal tissue damage were observed. The tomatoes had score 1 of Grierson and Kader's table 6.6 in all treatments.

Overall visual quality of tomatoes under all treatments was also excellently good, essentially no symptoms of deterioration were noticed. They had the score 9 of the table 6.7 (GRIERSON and KADER 1986).

Also no symptoms of physical damage in any of the treatments could be detected. Fruits from treated plants had score 1 of fruit ripening and quality table 6.8 (GRIERSON and KADER 1986).

Ripening and fruit quality studies showed that none of the salt treated tomatoes deteriorated their quality. On the other hand, salt stress enhanced the sweetness of the tomatoes by increasing glucose and fructose contents and improved the quality by increasing the concentrations of important acids such as ascorbic acid, citric acid etc. Other authors also report that increasing salt stress always improves fruit quality (ADAMS 1988, HOLDER and CHRISTENSEN 1988) and flavour of tomatoes (HOLDER and CHRISTENSEN 1988).

References

ABDUL-KADIR, S. M. and G. M. PAULSEN, 1982: Effect of salinity on nitrogen metabolism in wheat. J. Plant Nutri. *5,* 1141–1151.

ADAMS, P., 1988: Some responses in tomatoes in NFT to sodium. In: Proceedings International Congress on Soilless Culture, International Society for Soilless Culture. Wageningen, Netherlands, 59–71.

AL-RAWAHY, S. A., J. L. STROEHLEIN and M. PESSARAKLI, 1990: Effect of salt stress on dry matter production and nitrogen uptake by tomatoes. J. Plant Nutri. *13,* 567–577.

ATTENBURROW, D. C. and P. L. WALLER, 1980: Sodium chloride; its effect on nutrient uptake and crop yields with tomatoes in NFT (nutrient film technique). Acta Hortic. *98,* 229–236.

AYOUB, A. I., 1974: Causes of intervarietal differences in susceptibility to sodium toxicity in Phaseolus vulgaris. J. Agric. Sci. *83,* 539–543.

BERNSTEIN, L., 1963: Osmotic effect adjustment of plant to saline media: II. Dynamic phase. Amer. J. Bot. *50,* 360–370.

BOEHRINGER-MANNHEIM, 1989: Methoden der biochemischen Analytik und Lebensmittelanalytik. Boehringer-Mannheim GmbH, Biochemica, 6800 Mannheim 31, Germany.

CRAMER, G. R., A. LÄUCHLI and V. S. POLITO, 1985: Displacement of Ca^{2+} by Na^+ from the plasmalemma of root cells. A primary response to salt stress. Physiol. Plant *79,* 207–211.

CRAMER, G. R., E. EPSTEIN and A. LÄUCHLI, 1991: Effect of sodium, potassium and calcium on salt stressed barley: II. Elemental analysis. Physiol. Plant. *81,* 197–202.

CUSIDO, R. M., J. PALAZON, T. ALTABELLA and C. MORALES, 1987: Effect of salinity on soluble protein, free aminoacids and nicotin contents in Nicotiana rusticana L. Plant and Soil *102,* 55–60.

EPSTEIN, E. and D. W. RAINS, 1987: Advances in salt tolerance. In: GABELMANN, H. W. and B. C. LOUGHMAN (eds.): Genetic Aspect of Plant Mineral Nutrition. Martinus Nijhoff Publ., Dordrecht/Boston/Lancaster, 113–125.

FRANCOIS, L. E., T. J. DONOVAN, E. V. MAAS and G. I. RUBENTHALER, 1988: Effect of salinity on grain yield, quality, vegetative growth and germination of Triticale. Agron J. *80,* 642–647.

FLOWERS, T. J. and A. R. YEO, 1986: Ion relations of plants under drought and salinity. Austral. J. Plant Physiol. *13,* 75–91.

FLOWERS, T. J., P. F. TROKE and A. R. YEO, 1977: The mechanism of salt tolerance in halophytes. Ann. Rev. Plant Physiol. *28,* 89–121.

FROTA, J. N. E. and T. C. TUCKER, 1978: Absorption rates of ammonium and nitrate by red kidney beans under salt and water stress. Soil Sci. Soc. Am. J. *42,* 753–756.

GARCIA-REINA, G., V. MORENO and A. LUQUE, 1988: Selection for NaCl tolerance in cell culture of three Canry Island tomato land races. II. Inorganic ion in tolerant calli and somaclones. J. Plant Physiol. *133,* 7–11.

GRATTAN, S. R. and E. V. MAAS, 1988: Effect of salinity on phosphate accumulation and injury in soybean. I. Influence of $CaCl_2$/NaCl ratios. Plant and Soil *105,* 25–32.

GREENWAY, H. and R. MUNNS, 1980: Mechanism of salt tolerance in non-halophytes. Ann. Rev. Plant Physiol. *31,* 149–190.

GRIERSON, D. and A. A. KADER, 1986: Fruit Ripening and Quality. In: ATHERTON, J. G. and J. RUDICH (eds.): The Tomato Crop., Chapman and Hall, London/New York, 241–280.

HAJJI, M. C. and C. GRIGNON, 1985: Identifications des transports de K^+(Rb) affectes par NaCl dans la racine du laurier-rose. Physiol. Veg. *23,* 3–12.

HE, T. and G. R. CRAMER, 1992: Growth and mineral nutrition of six rapid-cycling Brassica species in response to seawater salinity. Plant and Soil *139,* 285–294.

HERNANDO, V., L. JIMENO and C. CADAHIE, 1967: Effect of sodium on nitrogen nutrition of tomatoes. A. Edafol. Agrobiol. *26,* 1147–1159.

HOLDER, R. and M. H. CHRISTENSEN, 1988: The effect of electrical conductivity on growth, yield and composition of cherry tomatoes grown on rockwool. In: INTERNATIONAL SOCIETY FOR SOILLESS CULTURE (ed.): Proceedings International Congress on Soilless Culture. Wageningen, Netherlands, 213–228.

HSIAO, T. C., E. ACEVEDO, E. FERRER and D. W. HENDERSON, 1976: Water stress, growth and osmotic adjustment. Phil. Trans. R. Soc. London (B) *273,* 479–500.

KAFKAFI, U., N. VALORAS and J. LETEY, 1982: Chloride interaction with nitrate and phosphate nutrition in tomato (Lycopersicum esculentum Mill.). J. Plant Nutr. *5,* 1369–1385.

LANGDALE, G. W. and J. R. THOMAS, 1971: Soil salinity effects on absorption of nitrogen, phosphorus and protein synthesis by coastal bermudagrass. Agron. J. *63,* 708–711.

LOOS, H. und P. WIDMOSER, 1986: Einsatz der Taupunkt-Methode zur Charakterisierung von Matrix- und osmotischem Potential in einer Gefäßkultur mit unterschiedlichen Salzgehalten. Z. Pflanzenernährung und Bodenkunde *149,* 572–581.

LUQUE, A. A. and F. T. BINGHAM, 1981: The effect of the osmotic potential and specific ion concentration of the nutrient solution on the uptake and reduction of nitrate by barley seedlings. Plant and Soil *63,* 227–237.

MAAS, E. V. and C. M. GRIEVE, 1987: Sodium induced calcium deficiency in salt-stressed corn. Plant Cell Environ. *10,* 559–564.

MAHAJAN, T. S. and K. R. SONAR, 1980: Effect of NaCl and Na_2SO_4 on dry matter accumulation and uptake of N, P and K by wheat. J. Maharashtra Agri. Univ. *5,* 110–112.

MATOH, T., J. WATANABE and E. TAKAHISHI, 1987: Sodium, potassium, chloride and betaine concentrations in isolated vacuoles from salt-grown Atriplex gmelini leaves. Plant Physiol. *84,* 173–177.

MATSUMOTO, H. and G. C. CHUNG, 1990: Physiological responses to salinity of barley and cucumber differing in NaCl tolerance: Changes of H^+ transport and H^+ ATPase activity under salinity. Proc. 14th Intern. Cong. in Soil Sci., IV 71–76.

McCree, K. J., 1986: Whole plant carbon balance during osmotic adjustment to drought and salinity stress. Austral. J. Plant Physiol. *13,* 33–43.
McCue, K. F. and A. D. Hanson, 1992: Effect of salinity on the expression of betaine aldehyde dehydrogenase in leaves: Investigation of hydraulic, ionic and biochemical signals. Austral. J. Plant Physiol. *19,* 555–564.
Palfi, G., 1963: The effect of sodium salts on the nitrogen, phosphorus, potassium, sodium and amino acids contents of rice shoots. Plant and Soil *22,* 127–135.
Pessarakli, M. and T. C. Tucker, 1985: Uptake of nitrogen-15 by cotton under salt stress. Soil Sci. Soc. Am. J. *49,* 149–152.
Pessarakli, M. and T. C. Tucker, 1988: Dry matter yield and nitrogen-15 uptake by tomatoes under chloride stress. Soil Sci. Soc. Am. J. *52,* 698–700.
Pessarakli, M., J. T. Huber and T. C. Tucker, 1989: Dry matter yield, nitrogen absorption and water uptake by sweet corn under stress. J. Plant Nutr. *12,* 279–290.
Plaut, Z. and C. M. Grieve, 1988: Photosynthesis of salt-stressed maize as influenced by Ca:Na ratios in the nutrient solution. Plant and Soil *105,* 283–285.
Rathert, G., 1983: Effect of high salinity stress on mineral and carbohydrate metabolism of two cotton varieties. Plant and Soil *73,* 247–256.
Robinson, S. P. and G. P. Jones, 1986: Accumulation of glycinebetaine in chloroplast provides osmotic adjustment during salt stress. Austral. J. Plant Physiol. *13,* 659–668.
Ryan, J., S. Miyamoto and J. L. Stroehlein, 1975: Salt and specific ion effects on germination of four grasses. J. Range Manage. *28,* 61–64.
Strogonov, B. P., 1964: Physiological basis of salt tolerance of plants. Acad. Sci. USSR (Translated from Russian). Israel program for scientific translation. Jerusalem, 279.
Torres, B. C. and F. T. Bingham, 1973: Salt tolerance of Mexican wheats. I. Effect of NO_3 and NaCl on mineral nutrition, growth and grain production for four wheats. Soil Sci. Soc. Am. Proc. *37,* 711–715.
Ullah, S. M., G. Soja and M. H. Gerzabek, 1989: Nährstoffaufnahme, Gaswechsel und Wasserhaushalt von Pferdebohnen *(Vicia faba* L.*)* unter Salzstreß. OEFZS-4514, LA-233/89.
Ullah, S. M., G. Soja and M. H. Gerzabek, 1993: Ion uptake, osmoregulation and plant-water relations in faba beans *(Vicia faba* L.*)* under salt stress. Die Bodenkultur *44,* 291–301.
Wood, J. N. and D. F. Gaff, 1989: Salinity studies with drought-resistant species of Sporobulus. Oecologia *78,* 559–564.
Wyn Jones, R. G. and R. Storey, 1981: Betaines. In: Paleg, L. G. and D. Aspinal: Physiology and Biochemistry of Drought Resistance in Plants. Academic Press, Sydney, 172–204.

(Manuskript eingelangt am 28. Februar 1994, angenommen am 14. Juni 1994)

Anschrift der Verfasser:

Prof. Dr. Shah M. Ullah, Department of Soil Science, Dhaka University, Dhaka 1000, Bangladesh; Univ.-Doz. Dr. Martin H. Gerzabek and Dr. Gerhard Soja, Division of Life Sciences, Austrian Research Centre Seibersdorf, A-2444 Seibersdorf, Austria