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Effect of a Saline Nutritional Regime on Tomato Fruit Yield and on Enhancement of Fruit Quality

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خلاصة : أجريت دراسة على أثر محلول غذائي مالح في انتاج خمسة أصناف من الطماطم ونوعيتها، هي: سي.إل. إن ٤٢٥، وبيرسون، ونابولي، وهيمار، وسييرا. تكونت المعاملات من، (١): محلول هوجلاند، كتجربة حاكمة (ت ك ٢,٥ م س سم -١)، (٢): محلول هوجلاند + ٥٠ ملمول كلوريد الصوديوم (ت ك ٧,٤٦ م س سم -١) (٣): محلول هوجلاند + ٥٠ ملمول كلوريد الصوديوم + ٤ ملمول كبريتات البوتاسيوم + ٢ ملمول أورثوفسفور (ت ك ٨,٣١ م س سم -١) (٤): كما في ٣ حتى ٥٠٪ من الأزهار ثم اضافة محلول الهوجلاند فقط كما في التجربة الحاكمة، (٥): كما في ٣ حتى ٥٠٪ من الأزهار، وبعدها تم تخفيض تركيز كلوريد الصوديوم إلى ٢٥ملمول (ت ك ٥,٨٧ م س سم -١). بدأت المعاملات عندما بلغ عمر النباتات سبعة أسابيع، وزرعت بادرات الطماطم في اسطوانات من إل بي في سي (قطر ١٥ سم وإرتفاع ٢٧ سم) بها رمل كوارتز. وتم حصد الثمار أسبوعياً لمدة عشرة أسابيع عند الاحمرار. التجربة الحاكمة أعطت معدلاً للإنتاج أكبر من المعاملات المالحة إلا أن معاملات المحلول الغذائي المالح كانت ذات حموضة أكثر ونسبة عالية من المواد الصلبة الذائبة والكلية مما يدل على نوعية أفضل من الثمار عنها في التجربة الحاكمة ومن الأصناف الخمسة انتجت عينة هيمار أعلى معدل للثمار تليها بيرسون. وكانت نابولي الأكثر تأثراً بالملوحة والعينة سييرا الأقل جودة.

ABSTRACT: The effect of a saline nutritional regime on tomato (*Lycopersicon esculentum* Mill.) fruit yield and fruit quality enhancement for five cultivars (CLN 425, Pearson, Napoli, Hymar, and Sierra) was studied. The saline nutrient treatments consisted of (i) a control, Hoagland's solution (EC=2.5 mScm^{-1}), (ii) Hoagland's solution + 50 mM NaCl (EC=7.46 mScm^{-1}), (iii) Hoagland's solution + 50 mM NaCl + 4 mM K_2SO_4 + 2 mM H_3PO_4 (EC=8.31 mScm^{-1}), (iv) same as in (iii) but applied when plants were at 50% flowering, then the plants were irrigated with Hoagland's solution as in the control, and (v) same as in (iii) until the plants were at 50% flowering, thereafter NaCl concentration was reduced to 25 mM (EC=5.87 mScm^{-1}). Plants were seven weeks old at the start of the saline treatments. Each plant was in PVC cylindrical pots (15 cm diameter and 27 cm height) containing washed quartz sand. Fruits were harvested once weekly for ten weeks at incipient red. The control gave a higher fruit yield than the saline treatments. However, the tomato fruits from the saline treatments had higher titratable acidity, higher total soluble solids, and higher total solids indicating better quality of the fruits than those from the control. Of the five cultivars studied, Hymar had the highest fruit yield followed by Pearson. Hymar's quality was also highest, followed by CLN 425. Napoli was the most susceptible to salinity and Sierra had the lowest quality.

In many areas of the world farmers have to use saline water to irrigate their crops because non-saline water is limited or unavailable. In the Sultanate of Oman, this is particularly true in the coastal strip where overpumping of water from underground aquifers has led to sea water intrusion into the aquifers, resulting in increased salinity levels of irrigation water. Soil salinity accumulates at a fast rate as irrigation water evaporates from the soil and if adequate leaching is not allowed. High salinity of soil solution reduces plant growth and its yield (Al-Rawahy et al. 1992; Ho et al. 1987; Pessarakli et al. 1989). However, it has been found that saline irrigation improves fruit quality of tomatoes (Lapushner et al. 1986; Pasternak et al. 1986). High electrical conductivity (EC) in the soil solution or hydroponic medium increased the concentration of total soluble solids (TSS) and therefore improved the flavour of tomato fruit (Cornish and Nguyen, 1989). Under saline conditions of soil solution, Cornish (1992) found that the flavour of salad tomatoes and the value of processing qualities are closely related to the concentration of total soluble solids (TSS) in the fruit. The desirable characteristics in salad and processed tomatoes were obtained as a result of irrigating the tomato plants with saline water in greenhouses (Ehret and Ho, 1986; Adams, 1988; and Charbonaeau et al. 1988), on sand dunes (Mizrahi et al. 1988), and under field conditions (Lapushaer et al. 1986; Pasternak et al. 1986; and Mitchell et al. 1991).

Tomato fruits should have adequate level of

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TABLE 1

Tomato fruit yield (kg/plant) for the five cultivars under five saline treatments.

CULTIVAR	NUTRIENT SOLUTIONS WITH FULL-STRENGTH HOAGLAND FORMULATION					OVERALL MEAN
	Control	NaCl	NaCl + K + P			
			Up to the end of the experiment	At 50% Flowering		
				Same as control	NaCl was reduced to 25 mM	
	I	II	III	IIIA	IIIB	
CLN 425	C 1.04 a	B 0.46 a	BC 0.57 a	C 0.82 a	BC 0.72 a	0.72 C
PEARSON	AB 2.29 a	AB 0.63 c	AB 1.10 c	B 1.77 ab	AB 1.32 bc	1.42 B
NAPOLI	B 2.07 a	AB 0.60 b	C 0.44 b	C 0.67 b	C 0.59 b	0.87 C
HYMAR	A 2.75 a	A 1.15 b	A 1.31 b	A 2.81 a	A 1.59 b	1.92 A
SIERRA	C 1.16 a	B 0.34 b	C 0.45 b	C 0.94 ab	C 0.60 ab	0.70 C
OVERALL MEAN	1.86 a	0.64 d	0.77 cd	1.40 b	0.96 c	---

Means within columns and rows, having the same letter are not significantly different from each other at 5% level (LSD) (Capital letters for columns and small letters for rows).

acidity since organic acids, especially citric acid, are important constituents of tomato flavour. The acidity of tomato products is influenced by organic acid and potassium contents and needs to be higher than the threshold value to prevent microbial spoilage after processing (Powers, 1976). According to Stevens et al. (1977), improved tomato flavour can be achieved via increased TSS and acid content. Titratable acidity and soluble solids content were responsible for most of differences in overall flavour intensity among different hybrids. In his study with tomatoes, Adams (1991) found that the data supports a specific role for K in controlling fruit acidity; but he also demonstrated that much of the increase in acidity of the fruit juices was due to salinity rather than to K per se.

Phosphorus has an important role in the quality of tomato fruits because of its effect on pH. Titratable acidity and pH are crucial to tomato quality because of their effects on flavour and processing characteristics (Stevens and Paulson, 1973). Awad et al. (1990) reported that increasing P fertilization enhanced the tolerance of tomato plants to high salinity. They found that at 0.1, 1.0, and 10 mM P, the NaCl concentration that reduced yields of fruit by 50% were 58, 72, and 130 mM, respectively. They also found that a high P concentration decreased Na and increased K concentration in immature leaves.

The objectives of this study were to evaluate the effects of saline nutrient regime on performance of five tomato cultivars in fruit yield by weight and by fruit number and enhancement of tomato fruit quality in terms of total soluble solids, titratable acidity and total solids.

Materials and Methods

Tomato seedlings were established in a standard potting mix in the greenhouse. Five tomato cultivars CLN 425, Pearson, Napoli, Hymar and Sierra were used. At five weeks after emergence, the seedlings were transferred to PVC cylindrical pots (15 cm diameter and 27 cm height) containing washed quartz sand. Nutrient solutions were pumped from holding tanks with a submersible pump into tubes that fed plants in the PVC pots. This consisted of five separate units. In each unit, basal nutrient solution (Hoagland's solution) and saline treatments were fed by an emitter tube drip system from a 70-L polythene reservoir. Solutions in all tanks were pumped intermittently (10 min on:10 min off) for 30 minutes using electric submersible pumps. Solution pH was adjusted with NaOH or H_2SO_4 to 5.8 $\pm$ 0.2 for all solutions. The treatments were applied daily. The system was controlled by a mechanical timing system. Initial irrigation of all the plants was applied with a control solution consisting of a half-strength Hoagland's solution in water from the mains (EC=0.75 $mScm^{-1}$) for a period of two weeks after transplanting. This study was conducted in a greenhouse at the Agricultural Experiment Station of Sultan Qaboos University. The range in temperatures in the greenhouse was from 18°C to 28°C with a mean daily sunlight of 11.5 hours.

The saline treatments were as follows: (i) control in which full-strength Hoagland's solution was mixed with the mains (tap) water resulting in EC of 2.5$mScm^{-1}$ (Treatment I), (ii) same solution as in (i) + 50 mM NaCl resulting in EC of 7.46 $mScm^{-1}$ (Treatment II),

TABLE 2

Number of tomato fruits harvested per plant for the five cultivars under five saline treatments.

CULTIVAR	NUTRIENT SOLUTIONS WITH FULL-STRENGTH HOAGLAND FORMULATION					OVERALL MEAN
	Control	NaCl	NaCl + K + P			
			Up to the end of the experiment	At 50% Flowering		
				Same as Control	NaCl was reduced to 25 mM	
	I	II	III	IIIA	IIIB	
CLN 425	B 26.33 a	B 19.33 a	AB 20.67 a	AB 27.67 a	A 23.67 a	23.53 BC
PEARSON	B 32.00 a	AB 28.67 a	AB 29.00 a	AB 26.00 a	A 30.33 a	29.20 B
NAPOLI	A 78.33 a	A 48.00 b	A 34.67 bc	B 20.00 c	A 33.33 bc	42.89 A
HYMAR	B 25.67 a	B 23.00 a	AB 28.67 a	A 41.00 a	A 29.67 a	29.60 B
SIERRA	B 24.33 a	B 16.67 a	B 13.33 a	B 15.00 a	A 18.67 a	18.67 C
OVERALL MEAN	37.33 a	27.13 a	25.27 a	27.73 a	26.40 a	---

Means within columns and rows, having the same letter are not significantly different from each other at 5% level (LSD) (Capital letters for columns and small letters for rows).

TABLE 3

Total soluble solids (TSS) percent for the five cultivars under the five saline treatments.

CULTIVAR	NUTRIENT SOLUTIONS WITH FULL-STRENGTH HOAGLAND FORMULATION					OVERALL MEAN
	Control	NaCl	NaCl + K + P			
			Up to the end of the experiment	At 50% Flowering		
				Same as Control	NaCl was reduced to 25 mM	
	I	II	III	IIIA	IIIB	
CLN 425	4.71	6.72	6.61	5.34	6.20	5.92 B
PEARSON	4.64	7.50	6.18	4.19	6.32	5.77 BC
NAPOLI	4.50	5.86	7.11	3.97	5.25	5.34 C
HYMAR	5.38	7.81	8.52	6.34	8.13	7.23 A
SIERRA	3.38	5.04	5.28	3.95	4.78	4.49 D
OVERALL MEAN	4.52 c	6.59 ab	6.74 a	4.76 c	6.14 b	---

Means within column and row, having the same letter are not significantly different from each other at 5% level (LSD) (Capital letters for columns and small letters for rows).

TABLE 4

Titratable acidity percent for the five cultivars under the five saline treatments.

CULTIVAR	NUTRIENT SOLUTIONS WITH FULL-STRENGTH HOAGLAND FORMULATION					OVERALL MEAN
	Control	NaCl	NaCl + K + P			
			Up to the end of the experiment	At 50% Flowering		
				Same as Control	NaCl was reduced to 25 mM	
	I	II	III	IIIA	IIIB	
CLN 425	0.26	0.32	0.28	0.26	0.32	0.29 A
PEARSON	0.12	0.22	0.21	0.11	0.19	0.17 C
NAPOLI	0.19	0.24	0.28	0.18	0.27	0.23 B
HYMAR	0.16	0.27	0.29	0.24	0.25	0.24 B
SIERRA	0.07	0.22	0.25	0.14	0.24	0.18 C
OVERALL MEAN	0.16 b	0.25 a	0.26 a	0.19 b	0.25 a	---

Means within column and row, having the same letter are not significantly different from each other at 5% level (LSD) (Capital letters for columns and small letters for rows).

(iii) same solution as in (ii) + 4 mM K_2SO_4 + 2 mM H_3PO_4 resulting in EC of 8.31 $mScm^{-1}$ until the end of the experiment (Treatment III), (iv) same as in (iii) but until plants were at 50% flowering, then the plants were irrigated with just Hoagland's solution as in the control (Treatment IIIA), and (v) same as in (iii) until the plants were at 50% flowering, thereafter NaCl concentrations was reduced to 25 mM resulting in EC of 5.87 $mScm^{-1}$ (Treatment IIIB).

Each treatment was replicated three times. Five plants from each tomato cultivar were used in each of the five treatments. Thus, in each replication there were 25 plants.

Fruits were harvested weekly for ten weeks at incipient red. They were then counted and weighed. Samples from each harvest were used to determine % TSS, % titratable acidity, and % dry matter. The % TSS was determined by a hand-held refractometer (American Optical Corp.). Titratable acidity was determined by crushing 5 g fruit sample, boiling in 200 ml distilled water for 15 minutes, then titrating 50 ml of the aliquot with 0.1N NaOH. The acidity was computed as percent citric acid. The data collected in this study was analyzed by Analysis of Variance (ANOVA) procedure and the means were separated by the least significant difference (LSD) test at the 0.05 level of confidence.

Results and Discussion

FRUIT YIELD: The tomato yield (kg/plant) showed that the control overall mean had a 25% higher yield than that produced by treatment IIIA overall mean, 48% higher than treatment IIIB, and 66% higher than treatment II that had the lowest yield (Table 1). For example, the control (I) produced 1.86 kg/plant while treatment IIIA produced only 1.40 kg/plant, a 25% difference. In spite of the 10% increase in salinity in treatment III as compared to treatment II there was no decrease in yield in treatment III as compared to treatment II. This indicates that the extra K and P included in treatment III had an enhancement effect of maintaining the productivity at a higher salinity level. Similar results were obtained by Awad et al. (1990) and Adams (1991). At 50% flowering, treatment IIIA overall mean was subjected to same conditions as the control (treatment I) overall mean but its yield was lower than that of treatment I overall mean because of its reduction in its vegetative growth induced by the saline treatment up to the 50% flowering stage. However, with the exception of Napoli cultivar that had statistical difference between treatments I and IIIA means, the other cultivars showed no statistical differences in their yields between the same two treatment means (I and IIIA). Cultivar CLN 425 was not affected by saline treatments since there were no significant differences between the salt treatment means and the control. Hymar had the highest yield at 1.92 kg/plant, which was about 26% higher than Pearson at 1.42 kg/plant and about 55% higher than the fruit yield of Sierra, Napoli and CLN425 at about 0.87 kg/plant. Compared to the control means, the saline treatments resulted in a 47% reduction in yield for Pearson, 76% reduction for Napoli, 38% reduction for Hymar, and a

50% reduction in yield for Sierra. Therefore, Napoli appears to be the most sensitive to saline treatments. The CLN 425 did not show significant difference to salinity.

Of the five cultivars, the fruit yield (number of fruits harvested/plant) for Napoli seemed to be the most sensitive to salinity (Table 2). This cultivar started with a mean number of fruits harvested per plant at 78 which was greater than 65% of the mean of the other four cultivars at 27 fruits/plant in the control (treatment I). In saline treatment II the number of fruits harvested per plant with Napoli fell from 78 to 48. This was a 39% decrease. In treatment IIIA it fell by 74% and that corresponded to the lowest number of fruits compared to the other cultivars with the exception of the yield from which Sierra was not statistically different.

The mean number of tomato fruits for the other cultivars were not affected by the saline treatments. Similar results were obtained by Cornish (1992). However, the mean size of fruits (by weight) for all the cultivars was reduced by the saline treatments except for CLN 425. The approximate size of the tomato fruits could be determined by using Tables 1 and 2. Considering the overall cultivar means, Hymar had 1.92 kg/plant (Table 1) with 29.60 fruits (Table 2) which resulted in the largest average fruit size of 65 g followed by Pearson with 49 g, then by Sierra with 38 g, then CLN 425 with 31 g and lastly by Napoli with 20 g average fruit size. The reduction of fruit size with saline treatments indicated the osmotic effect of salinity in limiting the water uptake. Pessarakli et al. (1989) also found that there was a decrease in water uptake of sweet corn due to salinity.

TOTAL SOLUBLE SOLIDS: The % TSS in the tomato fruit between the control (I) overall mean and IIIA treatment overall mean were not significantly different and had the lowest values among the treatments. The values for I and III were 4.52 and 4.76 percent, respectively (Table 3). This suggests that the saline pretreatment (NaCl + K + P) that continued until 50% flowering in IIIA had no effect on TSS since no fruit setting had yet occurred. Exposing control conditions as in treatment I at the flowering stage in treatment IIIA (from 50% flowering) ensured that at the start of fruit setting the plants would have already adjusted to the new regime. Similar reasoning can be applied to treatments II and IIIB which were also not significantly different from each other in their % TSS. The pretreatment (NaCl + K +P) that continued in IIIB until 50% flowering did not have an influence on the % TSS. It was the 25 mM NaCl in treatment IIIB exposed to the plants prior to fruit setting with continuation to the end of the study that had a direct influence on %TSS since its value was not significantly different from that of treatment II which also had NaCl. If treatment II had only 25 mM NaCl instead of 50 mM NaCl in the nutrient solution it would still have given the same value of % TSS as it had in this study (6.59% in treatment II is not significantly different from 6.14% in treatment IIIB).

The value of %TSS was highest in treatment III overall mean which was not significantly different from treatment II overall mean which, in turn, was not significantly different from treatment IIIB overall mean. Treatments I and IIIA had the lowest value of % TSS. Hymar cultivar had the highest overall mean followed by CLN425 and Pearson then Napoli and lastly by Sierra.

TITRATABLE ACIDITY: The same relationship that existed between treatments I overall mean and IIIA overall mean and that between treatments II and IIIB overall means for titratable acidity is reflected here as it had in % TSS (Table 4). This strengthens the above discussion that pretreatment before fruit setting had no effect on titratable acidity as it had no effect on TSS. It can also be inferred here that 25 mM NaCl in treatment IIIB can replace the 50 mM NaCl in treatment II since both the treatments had the same value of titratable acidity overall mean. The values of titratable acidity for cultivars ranging from high to low are CLN 425, Napoli and Hymar, and lastly Pearson and Sierra.

FRUIT DRY MATTER OR TOTAL SOLIDS: The overall treatment means show that all the saline treatment means had statistically higher total solids (TS) than the control (Table 5). Treatment IIIA had statistically the same value as the control since during the fruit setting the salinity stress had already been relieved and its effect was identical to the control from 50% flowering. The mean of the overall saline treatment means II, III and IIIB had 29% higher TS than the mean of I and /IIIA overall means. As for the overall cultivar means, Hymar had the highest value followed by CLN 425, Pearson, Napoli, and lastly by Sierra that had the lowest TS. Mitchell et al. (1991) found that the increased dry matter in saline treatments was due to decreased water import by the fruit resulting in size reduction.

Conclusions

The results of this study indicate that in spite of the reduced tomato fruit yield (kg/plant) that was caused by the saline nutrient treatments in all cultivars but one, there had been a general improvement in the quality of tomato fruit as indicated by its increase in TSS, titratable acidity and dry matter (TS) contents for all the five cultivars. The tomato fruit yield (kg/plant) was highest in the control and lowest in the NaCl (treatment II). The additional K and P in the treatments III had an enhancement effect of at least maintaining the yield the

TABLE 5

Tomato fruit dry matter or total solids (TS) percent for five cultivars under five saline treatments.

CULTIVAR	NUTRIENT SOLUTIONS WITH FULL-STRENGTH HOAGLAND FORMULATION					OVERALL MEAN
	Control	NaCl	NaCl + K + P			
			Up to the end of the experiment	At 50% Flowering		
				Same as Control	NaCl was reduced to 25 mM	
	I	II	III	IIIA	IIIB	
CLN 425	7.49	9.80	9.29	7.48	9.03	8.62 B
PEARSON	6.15	10.08	8.53	5.94	9.23	7.99 BC
NAPOLI	5.93	8.60	8.78	5.43	7.21	7.19 CD
HYMAR	6.99	11.20	11.42	8.50	11.08	9.84 A
SIERRA	4.89	6.55	7.88	5.42	7.02	6.35 D
OVERALL MEAN	6.29 b	9.25 a	9.18 a	6.56 b	8.72 a	---

Means within column and row, having the same letter are not significantly different from each other at 5% level (LSD) (Capital letters for columns and small letters for rows).

same as in treatment II in spite of its higher salinity. Hymar cultivar had the highest yield followed by Pearson in the second place and in the third place were Sierra, Napoli and CLN 425. With the exception of Napoli, the saline treatments did not affect the number of fruits per plant. However, the size of the fruits were smaller with saline treatments due to the osmotic effects of salinity in limiting water uptake. The highest saline pretreatment until 50% flowering had some effect on reducing tomato fruit yield but had no effect on the quality of tomato fruit.

In many countries of the world with a developed food industry, a high soluble solids content is of major economic value not only to the tomato processing industry, but also for the fresh vegetable market. With proper management, a high soluble solids content is now also achievable in saline conditions. Finally, with the advent of industrialization taking place in Oman and with, for example, the establishment of University food science programs in the country, we can expect greater emphasis on standardization of different agricultural produce, including tomatoes. Close cooperation in agricultural research, for instance, between the College of Agriculture and the Ministry of Agriculture and Fisheries Resources in Oman, will play a key role in development of management practices that will allow crops to be grown under tolerable saline conditions in soil and water.

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