Potassium Affects Sodium Content in Tomato Plants Grown in Hydroponic Cultivation under Saline-sodic Stress

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Abstract. The tomato cultivars Edkawi and UC 82B (*Lycopersicon esculentum* Mill.) were grown hydroponically in a solution [electrical conductivity (EC) 2.4 dS·m⁻¹] containing 150 mM Na (EC 11.4 dS·m⁻¹), 37 mM of K (EC 14.1 dS·m⁻¹), or 75 mM of K (EC 19.7 dS·m⁻¹). The leaf Na content of 'Edkawi' and 'UC 82B' reached values of 1717 and 2022 mmol·kg⁻¹ dry weight at EC 19.7 dS·m⁻¹, respectively. The high levels of K in the hydroponic solution reduced the Na concentration in the roots, petioles, and stems, but not in the leaves. Potassium concentrations in the petioles of 'Edkawi' and 'UC 82B' reached values of 2655 and 2966 mmol·kg⁻¹ dry weight, respectively. At these elevated ECs, the Ca concentrations in the leaves of 'Edkawi' and 'UC 82B' were 30% and 40% lower than in the control, respectively. The elevated rates of K improved the fruit : flower ratio of 'UC 82B', but the high salinity of the solution reduced yields significantly. Plant fresh weight and root dry weight of 'UC 82B' were most affected by high EC levels. The elevated levels of K used in this study did not increase yield, but K ions can adjust to Na uptake.

Salt stress of hydroponically grown plants is caused by high ion concentrations in the fertilizer solution, and can significantly reduce yields of hydroponically grown vegetables (Flowers and Yeo, 1989). Salinity can alter the uptake mechanisms of nutrient elements, resulting in variations in relationships between ions (Lauchli and Epstein, 1990). Plant symptoms occurred when Na and Cl were substituted for K, NO₃, and Ca. An important aspect of salinity stress is the interaction between Na and K ions (Greenway and Munns, 1980).

Sodium, provided in low amounts, stimulates growth and development of plants and can improve the organoleptic characteristics of the edible parts (Satti et al., 1996). However, high concentrations of Na in the soil inhibit plant growth and reduce commercial yield (Graifenberg et al., 1993, 1996).

Potassium is an essential cation for plants. The optimal concentration of K ranges from 2% to 5% of the dry weight of the vegetative parts. Its absorption is selective and is closely affected by metabolic activity of the plant (Marschner, 1986). Potassium regulates the osmotic potential of glycophyte tissues, and therefore plays a role in water relations (Lauchli and Pflüger, 1978).

In some horticultural crops grown under salt-sodic conditions, high Na concentrations

in the soil reduce K content and increase Na content in the tissues (Graifenberg et al., 1995, 1996). Schachtman and Schroeder (1994) and Rubio et al. (1995) assumed that a common mechanism of absorption for K and Na ions in higher plants could exist and was regulated by the concentration of the two ions present in the substrate. Therefore, elevated levels of K could modulate the absorption and the transport of Na and limit the damages attributed to it. The purpose of this experiment was to determine the effects of high amounts of K in the hydroponic solution on the uptake and accumulation of Na in tomatoes.

Materials and Methods

Plant material. On 14 Feb. 1997, seeds of 'Edkawi' tomato, with an indeterminant growth habit, and of 'UC 82B', with a determinant growth habit, were sown, one seed per cell, in 160-cell, 18-cm³ polystyrene trays, containing a substrate composed of perlite and vermiculite (50/50) plus 160, 78.6, or 179 mg·L⁻¹ of N, P, and K, respectively.

Growing conditions. After 2 weeks, the seedlings were placed in 75-cm³ pots filled with 4-mm-diameter expanded clay. These pots were placed in 20 × 10 × 5 unit plastic containers and watered with a standard nutritive solution for 8 d. The seedlings were then transferred into the hydroponic culture system, which provided constant control of the nutrient solution and environmental parameters. The system consisted of a 100-L solution tank, a circulation pump (model Vxm8/35; "Pedrollo", Verona, Italy), and a closed-loop recirculating system. The hydroponic culture system was previously disinfected with a commercial solution of NaOCl (8%) for 24 h. The culture-system was then rinsed

several times with tap water to eliminate residual NaOCl.

Treatments. All seedlings were grown in a standard hydroponic solution containing 3 mM K₂SO₄, 5 mM Ca(NO₃)₂, 1 mM H₃PO₄, 20 mg·L⁻¹ Sequestrene 138 (Ciba-Geigy, Varese, Italy), and 20 mg·L⁻¹ Microfol (E.D. S.p.A., Pistoia, Italy) [electrical conductivity (EC) 2.4 dS·m⁻¹]. A preliminary experiment was performed by growing the 'Edkawi' seedlings in hydroponic solutions containing 2, 50, 100, 150, or 200 mM of NaCl in order to select the appropriate Na concentration. The 150-mM solution reduced yield to 50% of the control and was used in the next trials. The three treatment solutions contained 150 mM of NaCl, plus K₂SO₄ at 3, 18.75, or 37.5 mM, corresponding to 11.4, 14.1, and 19.7 dS·m⁻¹ EC, respectively.

According to the hypothesis of Rubio et al. (1995), we should have had to use equimolar concentrations of K and Na ions in the hydroponic solutions. However, the amount of K ions supplied increased the EC too much and induced the formation of insoluble compounds. For this reason we utilized 37.5 and 75 mM of K to reach the highest possible concentration of ions that avoided precipitation.

The pH of the solution was maintained at 6.1–6.5 with sulfuric acid. The solutions were renewed every 7 d.

The experimental design was a randomized complete-block with four replicates of 16 plants per treatment.

Data collection. Yield data were collected from 15 May to 28 June. Only entirely red fruit were harvested twice per week, weighed, and dried for ion measurements. Whole plants were harvested on 28 June for fresh weight determination and partitioned into roots, stems, and leaves for ion determinations. Petioles consisted of the main and secondary petioles of compound leaves. Leaves were lamina only. Plant tissues were oven-dried at 70 °C for 6 d before dry weights were determined. Flower and fruit numbers of the first three flower clusters were monitored every 2 d beginning with the appearance of the first flower.

Tissue analysis. For ion determinations, 2-g samples of dried, ground tissues were digested in 70% HClO₄ and concentrated HNO₃ (1:2 v/v). The Na, K, and Ca contents were then quantified using atomic absorption technology (model S11; Allied Analytical System, Waltham, Mass.).

Statistical analysis. Data were subjected to regression analysis, and SE was calculated (Jandel Scientific, 1986). The significance of differences between means were determined by using Duncan's multiple range test (SAS Institute, 1990).

Results and Discussion

Yield. The salinity and the methodology employed to study the plant responses under salt stress can seriously affect the process of uptake and transport of fertilizer ions. Our data suggest that increasing salinity in the substrate

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reduced both yield and plant fresh weight (Table 1), as reported for other vegetables (Graifenberg et al., 1993; Lauchli and Epstein, 1990; Munns and Termet, 1986). Regression analysis indicated that increasing the EC level reduced yield of both cultivars. The total number of fruit in all treatments was higher in 'UC 82B' than in 'Edkawi', but treatment 3 increased the total number of 'Edkawi' fruits with respect to the control treatment (data not reported). This was also reported by Satti and Al-Yahyal (1995). In 'UC 82B', both plant fresh weight and root dry weight declined as EC increased. Lopez and Satti (1996) reported that nutrient solutions with elevated amounts of K increased yield in cultivars with indeterminate growth habit. Our yield results can be attributed to the high EC, and to a low amount of N supplied in the nutrient solution. We used K_2SO_4 in place of KNO_3 , as did Lopez and Satti (1996), to avoid the effects of a positive interaction between K and nitrate ions on yield. The yield reduction was less evident in 'Edkawi' than in 'UC 82B'.

Flowering and fruit set. The ratio of fruit : flower in both cultivars decreased similarly until the EC of $11.4 \text{ dS} \cdot \text{m}^{-1}$ (75 mm K) was reached; the ratio for 'UC 82B' then started to increase while that for 'Edkawi' continued to decline (Fig. 1). This response might be related to the different flowering habits of these two cultivars.

These data differ from those reported by Satti and Al-Yahyal (1995), who obtained higher numbers of fruit per plant, particularly in indeterminate cultivars. We observed an increase in the number of fruit per plant in the determinate cultivar UC 82B. This controversial response can be ascribed to the well-known low production of fruits in the first clusters of 'Edkawi'.

Tissue Na concentration. Treatment 2 (150 mm Na) produced the maximum values of Na in the roots, stem, and petioles (Table 2), while treatment 4 produced the minimum values, as indicated by reductions of 44% and 34% in roots, 53% and 55% in stem, and 53% and 42% in petioles of 'Edkawi' and 'UC 82B', respectively. A different trend was evident in the leaves of both cultivars, which accumulated the maximum Na concentration in treatment 4. A significant increase in Na concentration in fruits was observed only in 'UC 82B'.

Tissue K concentration. Treatment 2 produced the lowest, and treatment 4 the highest, K concentrations in all plant parts of both cultivars (Table 2). Concentrations were highest in the petioles.

Besford and Maw (1975) reported a positive effect of K ions on flowering and pollination. In tomato cultivars with indeterminate growth habit, the rate of K uptake varied with the stage of growth and was closely correlated with fruit load. Adams and Windsor (1979) reported that K uptake in cultivars with indeterminate growth habit was extended and correlated with the blooming period. In tomatoes with determinate growth habit, the vegetative and reproductive phases of growth are shortened, thus creating an elevated requirement for K in a short time because of higher

Table 1. The effects of four different hydroponic solutions on yield, fresh weight, and dry weight of two tomato cultivars.

Treatment ^z	EC (dS·m ⁻¹)	K (mm)	Na (mm)	Yield (kg/plant)	Fresh wt (g/plant)	Dry wt		
						Root (g/plant)	Shoot (g/plant)	Total (% fresh wt)
<i>Edkawi</i>								
1 Control	2.4	6	2	1.565	910	20.1	104.9	13.7
2	11.4	6	150	0.865	879	19.7	102.7	13.9
3	14.1	37.5	150	0.761	795	17.5	83.7	12.7
4	19.7	75	150	0.629	777	17.2	79.2	12.3
Linear				*	NS	NS	NS	NS
Quadratic				*	NS	NS	NS	NS
<i>UC 82 B</i>								
1 Control	2.4	6	2	1.689	1116	24.6	88.6	10.2
2	11.4	6	150	0.743	897	19.8	76.1	10.7
3	14.1	37.5	150	0.602	709	15.2	51.8	9.5
4	19.7	75	150	0.418	621	14.1	40.2	8.7
Linear				*	*	*	NS	NS
Quadratic				*	NS	NS	NS	NS

²Standard solution = $3 \text{ mm K}_2\text{SO}_4$, $5 \text{ mm Ca}(\text{NO}_3)_2$, $1 \text{ mm H}_3\text{PO}_4$, $20 \text{ mg} \cdot \text{L}^{-1}$ Sequest. 138, $20 \text{ mg} \cdot \text{L}^{-1}$ Microfol; 2 = same plus 150 mm NaCl ; 3 = same plus 150 mm NaCl and $18.75 \text{ mm K}_2\text{SO}_4$; 4 = same plus 150 mm NaCl and $37.5 \text{ mm K}_2\text{SO}_4$.

NS,* Nonsignificant or significant at $P \leq 0.05$, respectively.

Fig. 1. The effects of four different hydroponic solutions on the fruit : flower ratio of the first three clusters of two tomato cultivars. Vertical bars indicate SE.

fruit load. Our data confirmed this trend. 'UC 82B', a determinant tomato cultivar, exhibited higher shoot K concentration and a higher fruit load than did 'Edkawi'.

Our data suggest a different distribution of K in tissues between the cultivars, particularly when the K concentration in the substrate was increased from 6 to 75 mm . From the beginning of hydroponic cultivation, both cultivars were grown in the presence of Na and K. This method resulted in a greater accumulation of K in the plant, particularly in the petiole, and with obvious differences in leaves and roots. These data can be explained by the different times at which ions are transported and accumulated in the tissues of both cultivars (Lauchli and Pflugler, 1978). Moreover, the high concentration of K detected in roots could cause a temporary arrest of the transport of Na ions in roots, petioles, and leaves. The roots of tomato

plants grown in hydroponic culture are fasciculate, long, and thin. This feature is correlated with a reduction of cell layers in the root cortex, which can contribute to higher rates of selective uptake of functional ions (Poljakoff-Mayber, 1975).

The accumulation of Na in both cultivars confirms that the Na ions always reached the leaves. But it is also evident that Na uptake did not interfere with K movement and accumulation.

'Edkawi' was less sensitive to salt stress than was 'UC 82B'. This tolerance is probably due to the characteristic of this cultivar to withhold sufficient amounts of active K ions in functional tissues such as roots (Taleinsk and Grunberg, 1994).

Tissue Ca concentration. Treatments 1 and 4 yielded the highest concentration in the root, and treatment 4 yielded the lowest accumula-

Table 2. Content of Na, K, and Ca (mmol·kg⁻¹ dry weight) in roots, stem, petioles, leaves, and fruit of two tomato cultivars as affected by four different hydroponic solutions.

Cultivar	Treatment ^z	EC (dS·m ⁻¹)	K (mm)	Na (mm)	Roots	Stem	Petioles	Leaves	Fruits
<i>Na content</i>									
Edkawi	1 Control	2.4	6	2	696 c ^y	174 d	391 d	283 d	126 a
	2	11.4	6	150	1478 a	413 a	1435 a	1457 b	165 a
	3	14.1	37.5	150	978 b	261 b	913 b	1327 c	171 a
	4	19.7	75	150	826 b	196 c	673 c	1717 a	176 a
UC 82B	1 Control	2.4	6	2	587 c	174 d	348 d	348 d	96 d
	2	11.4	6	150	1521 a	630 a	1739 a	1696 c	283 b
	3	14.1	37.5	150	1000 b	415 b	1217 b	1870 b	252 c
	4	19.7	75	150	1005 b	283 c	1012 c	2022 a	304 a
<i>K content</i>									
Edkawi	1 Control	2.4	6	2	217 c	524 c	754 c	690 b	665 b
	2	11.4	6	150	192 d	294 d	217 d	153 d	84 d
	3	14.1	37.5	150	1330 b	742 b	1470 b	639 c	458 c
	4	19.7	75	150	1790 a	1023 a	2455 a	1624 a	905 a
UC 82B	1 Control	2.4	6	2	243 c	511 c	716 c	550 c	524 c
	2	11.4	6	150	217 c	384 d	384 d	217 d	115 d
	3	14.1	37.5	150	882 b	972 b	1841 b	1040 b	578 b
	4	19.7	75	150	1048 a	1253 a	2966 a	1841 a	1026 a
<i>Ca content</i>									
Edkawi	1 Control	2.4	6	2	501 a	299 a	788 a	1088 a	201 a
	2	11.4	6	150	400 c	304 a	700 c	1050 b	150 b
	3	14.1	37.5	150	450 b	313 a	738 b	888 c	112 c
	4	19.7	75	150	375 d	225 b	538 d	738 d	83 d
UC 82B	1 Control	2.4	6	2	438 a	375 a	875 a	1425 a	300 a
	2	11.4	6	150	388 b	401 a	787 b	1250 b	251 b
	3	14.1	37.5	150	313 c	300 b	613 c	1063 c	201 bc
	4	19.7	75	150	288 d	275 b	500 d	850 d	156 d

^zStandard solution = 3 mm K₂SO₄, 5 mm Ca(NO₃)₂, 1 mm H₃PO₄, 20 mg·L⁻¹ Sequest.138, 20 mg·L⁻¹ Microfol; 2 = same plus 150 mm NaCl; 3 = same plus 150 mm NaCl and 18.75 mm K₂SO₄; 4 = same plus 150 mm NaCl and 37.5 mm K₂SO₄.

^yMean separation within parameters and columns by Duncan's multiple range test, *P* ≤ 0.05.

tion of Ca in the petioles, leaves, and fruits of both cultivars. The Ca concentration of the stem was not reduced significantly. The trend of Ca accumulation under our experimental conditions confirmed the data of Munns and Termot (1986).

In our experimental system, an oversupply of K in the presence of elevated Na did not increase yield.

Additional research is needed to assess new methods that allow faster transport of K than of Na ions in plants. Such a system could be useful in evaluating the potential capacity of K to protect against the deleterious effects of Na in higher plants.

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