Influence of Potassium and Genotype on Vitamin E Content and Reducing Sugar of Tomato Fruits

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Abstract. This research was conducted to determine the effect of potassium (K) and cultivar on important quality traits of tomato (*Solanum lycopersicum* L.), including reducing sugar, titratable acidity, and vitamin E content. Tomato plants were grown in a soilless system. Three K levels (low, middle, and high equal to 150, 300, and 450 mg·L⁻¹ in the nutrient solution, respectively) and three cultivars (SVR, Kabiria, and Esperanza) were compared. Among cultivars, Kabiria, which is characterized by smaller fruits, showed 23% higher total soluble solids (TSS) than the average of the other cultivars. ‘Kabiria’ also showed a total tocopherol (vitamin E) content (18.5 mg·kg⁻¹), markedly higher than SVR and Esperanza cultivars (12.2 and 10.3 mg·kg⁻¹, respectively). Increased K levels in the nutrient solution resulted in increased contents of TSS, reducing sugar contents and titratable acidity in tomato fruits. Also, the vitamin E content of tomato fruits was significantly affected by differing K concentrations in the nutrient solution.

Tomato (*Solanum lycopersicum* L.) is the second most produced vegetable around the world, behind the potato crop (FAO, 2008). At present, many new cultivars and hybrids are available for fresh consumption. Recently, several seed companies have released new “high-pigment” tomato cultivars characterized by higher content of the antioxidant lycopene. These cultivars have not been thoroughly investigated as far as cultivation requirements are concerned.

Potassium (K) is the most efficient cation for tomato plants and according to several authors, it plays a key role in the improvement of several quality traits in tomato fruits and in almost all vegetables (Adams, 1992; Bergmann, 1992; Chapagain and Wiesman, 2004; Dorais et al., 2001, 2008; Oded and Uzi, 2003). Unlike nitrogen, phosphorus, and sulfur, K is not a constituent of the organic matter, but its physiological functions in plants include enzyme activation, osmoregulation, photosynthesis, and translocation of

photosynthates into sink organs (Bergmann, 1992; Marschner, 1995). In muskmelon, fruits from plants receiving weekly foliar/spray K applications matured 2 d earlier and had significantly higher soluble solid concentration, total sugar, ascorbic acid (vitamin C), and beta-carotene content than fruits from plants without receiving any foliar K application (Lester, 2005).

In tomato, it has been reported that acid and reducing sugar contents, often correlated with K application, influence not only sweet and sour taste attributes, but also different flavor traits (Auerswald et al., 1999; Chapagain and Wiesman, 2004; Petersen et al., 1998).

Various antioxidant molecules confer high nutritional value to fresh tomatoes. Among them, the lipophilic tocopherols, known as vitamin E, have been shown to carry out essential functions in slowing or preventing degenerative disease processes in humans (Kaur and Kapoor, 2001; Traber and Sies, 1996). Of the four known tocopherol forms— α , β , γ , and δ — α -tocopherol is biologically the most active, having the highest vitamin E activity. Dietary vitamin E supplements contain commercially synthesized α -tocopherol, a racemic mixture of eight stereoisomers, which is less effective than the natural *RRR*- α -tocopherol; the latter possesses the highest level of biological activity (Brigelius-Flohé and Traber, 1999;

Kamal-Eldin and Appelqvist, 1996). Because natural vitamin E is synthesized only by photosynthetic organisms, plant foodstuffs such as vegetables, fruits, and specially seed oils are the main source for human dietary intake of vitamin E. Plant tissues vary enormously in their tocopherol content and composition. Generally, seeds and seed oils contain more γ -tocopherol than α -tocopherol; the opposite is true for green leaves. Beta-tocopherol and δ -tocopherol are the least abundant (Grusak and Della Penna, 1999; Schneider, 2005).

The recommended daily allowance for vitamin E is 15 mg tocopherol both for adult women and men (Della Penna, 2005) and is not easily achieved with the average diet. Therefore, it is of great interest to investigate those factors that can influence vitamin E content of largely consumed plant foods. On the other hand, there is a lack of scientifically based evidence regarding K effects on important quality traits of tomatoes such as reducing sugar and vitamin E contents.

The aim of the present study was to investigate how K and genotype can influence reducing sugar, titratable acidity, and vitamin E content of tomato fruits.

Materials and Methods

Cropping system and treatments. The experiment was carried out during the 2003 summer–winter season in a plastic (polymethacrylate) greenhouse at “La Noria” Experimental Farm of the Institute of Sciences of Food Production of the Italian National Research Council at Mola di Bari, (41°03' N, 17°04' E, 24 m a.s.l.).

Tomato plants were grown in a soilless system. Three K concentrations (low, middle, and high, respectively, equal to 150, 300, and 450 mg·L⁻¹ of nutrient solution) and three cultivars [two high-pigment (hp), ‘SVR’ and ‘Kabiria’, and ‘Esperanza’ no hp hybrid] were compared. A split-plot design with three replicates was used (K level into the plots and cultivars into the subplots). Each experimental unit contained eight plants. Tomato plants were transplanted on 5 Aug. at the four to five true leaf stage into rockwool slabs (length 1 m and width 20 cm). The slabs were placed on 26-cm wide troughs with 6-cm side banks covered by a plastic film with a distance of 25 cm between the plants and 130 cm between troughs (3.1 plant/m²). The nutrient solution was distributed using a drip irrigation system with pressure-compensated 8-L·h⁻¹ emitters with four emitter stakes, two per plant; and was supplied to maintain the excess drainage not higher than 20%.

Nutrient solution containing nitrogen (N), K, phosphorus, magnesium (Mg), sulfur (S), and calcium (Ca) at 150, 150, 50, 55, 30, and 150 mg·L⁻¹, respectively, was prepared using HNO₃ and the following salts: Ca(NO₃)₂ + 4H₂O, KNO₃, KH₂PO₄, MgSO₄ + 7H₂O, K₂SO₄. Well water used had the following characteristics: pH of 7.6 and electrical conductivity (EC) of 1.1 dS·m⁻¹; 3 (N-NO₃), 5 (K), 30 (Mg), 6 (S), 100 (Ca), 83 (sodium)

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and 120 (chlorine) mg·L⁻¹. KCl was added to reach higher K levels (300 mg·L⁻¹, which is the concentration commonly used in commercial conditions, and 450 mg·L⁻¹) in the nutrient solution. The ECs were 2.0, 2.3, and 2.6 dS·m⁻¹, respectively, for 150, 300, and 450 mg·L⁻¹ K in the nutrient solution. The pH of the nutrient solution was measured using a portable pH meter, HI 9023 (Hanna Instruments, Padova, Italy) and adjusted to 5.5 to 6.0 using 2 M H₂SO₄. Micronutrients were applied according to Johnson et al. (1957).

The plants were trained vertically and periodic operations of trailing, lateral stem, and basal leaf pruning were carried out. Minimum temperatures inside the greenhouse were set up to be higher than 12 °C day/10 °C night. Pollination was guaranteed by the introduction into the greenhouse of bumblebees (*Bombus terrestris*) at the full anthesis of the first cluster. Furthermore, integrated control of the principal pests was achieved by using chromotropic traps to monitor them; following release of predatory insects, parasitoids and localized treatments with selective active principles on the plant showed first symptoms of attack. Harvest started on 21 Oct. and finished on 7 Jan. Fruits were harvested at the red stage.

Qualitative analysis. Total soluble solids (TSS), titratable acidity, glucose, fructose, tocopherol, and dry matter (DM) were assessed on the ripe fruits picked up on 4 Nov.

TSS were determined using a portable reflectometer (Brixstix BX 100 Hs; Techni-quip Corporation, Livermore, CA).

Titratable acidity (TA) was determined by potentiometric titration with 0.1 M NaOH to pH 8.1 using 10 mL of juice. Results were expressed as a percentage of citric acid in the juice.

Glucose and fructose were determined on fruits homogenized at 3,000 rpm by ionic chromatography (Dionex model DX500; Dionex Corp., Sunnyvale, CA) with an amperometric detector (Santamaria et al., 2004).

Fruits were dried to a constant weight in a forced-draft oven at 65 °C for the determination of the dry weight.

The extraction of tocopherols was carried out as previously described (Serio et al., 2004). Briefly, tomato samples (2 g) ground in liquid nitrogen were incubated in a screw-capped tube with 10 mL 12% potassium hydroxide, 20% (v/v) ethanol, 0.1% (w/v) sodium chloride, and 3% (v/v) ethanol pyrogallol. After alkaline digestion at 70 °C for 30 min and subsequent cooling, 15 mL 1% (w/v) sodium chloride solution was added. The sample was then extracted twice with 15 mL n-hexane:ethyl acetate (9:1). The organic phase was collected, evaporated by Rotavapor (IKA, Labortechnik, Staufen, Germany), and the dry residue was dissolved in 1 mL 98% (v/v) methanol. A sample volume of 20 mL was separated by reverse phase (RP) high-performance liquid chromatography.

To determine tocopherols, chromatographic separation was performed by using a Beckman System Gold Apparatus (Beckman Instruments, Fullerton, CA). A RP-C18

Beckman Ultrasphere column was used as previously described (Caretto et al., 2002). Two programmable detectors, an ultraviolet-visible spectrophotometer (set at λ : 290 nm) and a spectrofluorimeter (λ excitation: 289 nm; λ emission: 325 nm) were connected in series. The spectrofluorimetric profiles were used to quantitatively determine tocopherols. The tocopherol content was calculated by means of standard calibration curves. Tocopherol pure standards were purchased from Calbiochem, Darmstadt, Germany.

TSS were assessed in quadruplicate, whereas DM, TA, glucose, fructose, and tocopherol analyses were performed in duplicate.

Statistical analysis. All data were analyzed using analysis of variance by means of the GLM PROC of the SAS software (SAS Institute Inc., Cary, NC). Statistical analysis was performed according to the General Linear Model Theory (Steel and Torrie, 1998), and for this purpose, all the experimental factors were considered as fixed. Least significant difference test was used for mean separation. Concerning K levels, to corroborate the main objectives of this research, orthogonal polynomial contrasts, with a single df level, were performed (Steel and Torrie, 1998).

Results and Discussion

While evaluating factors influencing fruit quality of new tomato genotypes, it is of great importance to assess possible induced changes on yield and its components. Generally, the average yield of tomato fruits per plant was not very high (2.83 kg/plant) as a result of the low average weight of the fruits and the low number of clusters per plant harvested. The total yield of tomato fruits was higher in 'SVR' and 'Esperanza' (2.99 and 2.96 kg/plant, respectively) than in 'Kabiria' (2.55 kg/plant), mainly as a result of the average weight of the fruits, 94 and 93 g for 'SVR' and 'Esperanza', respectively, whereas the mean fruit weight for 'Kabiria' was only 45 g/fruit. Interestingly, by increasing the potassium level in the nutrient solution, total yields and reject percentages did not change (Serio

et al., 2007). Although no significant differences resulted between K levels in the nutrient solution, the analysis carried out using orthogonal polynomial contrasts revealed an increased DM with increasing potassium levels in the nutrient solution ($P \leq 0.01$); among cultivars, 'Kabiria' registered a higher DM content than 'SVR' and 'Esperanza', 16% and 33%, respectively (Table 1).

Fruit K⁺ concentration was not influenced by K levels in the nutrient solution being on average 32 g·kg⁻¹ DM (Serio et al., 2007). Differently, fruit K⁺ concentration was influenced by genotypes (34 g·kg⁻¹ DM for 'Esperanza' versus 30 g·kg⁻¹ DM, on average, for the two hybrids hp, 'Kabiria' and 'SVR'; Serio et al., 2007).

TSS, glucose, and fructose increased linearly with increasing potassium levels in the nutrient solution ($P \leq 0.05$ for all three parameters; Table 1). Among cultivars, Kabiria showed the highest TSS content (23% more) compared with the mean of the other two cultivars and logically evinced by the lower average fruit weight (45 g) of the former one. Size of the fruit is an important trait for tomato fruit quality; an increased fruit size means higher water content and consequently lower TSS content (Santamaria et al., 2004). More recently, Balibrea et al. (2006) have reported that an increase of TSS in tomato fruits may depend on a higher sugar import and accumulation.

The increase of TSS together with the increase of two reducing sugars in the fruits of plants grown with the higher K levels in the nutrient solution (Table 1) confirm that K can play an important role in the configuration of quality profile in tomato fruits. Potassium is the most abundant cation present in the phloem sap (almost 80% of the total cations) as a consequence of sugar charging and transport mechanisms/processes through the phloem into sink organs (Cakmak, 2005). It is well known that potassium plays a key role in carbohydrate metabolism and photosynthesis (Marschner, 1995) and, as a consequence, an optimum potassium supply determines better sugar content into sink organs.

Table 1. Dry matter, total soluble solids (TSS), titratable acidity (TA), TSS/TA ratio, glucose, and fructose of tomato fruits in relation to potassium levels and cultivar.

	Dry matter (g/100 g ⁻¹ FM ^a)	TSS (°Brix)	TA (g/100 mL ⁻¹)	TSS/TA	Glucose (g/100 g ⁻¹ FM)	Fructose (g/100 g ⁻¹ FM)
K level (mg·L ⁻¹)						
150	5.17	4.8 b	0.29 b	16.55	1.20 b	1.20 b
300	5.24	5.1 ab	0.33 a	15.45	1.41 ab	1.48 a
450	5.46	5.2 a	0.34 a	15.29	1.47 a	1.56 a
Cultivar						
Esperanza	4.58 c ^b	4.7 b	0.31	15.16 b	1.33	1.29
Kabiria	6.07 a	5.7 a	0.32	17.81 a	1.39	1.51
SVR	5.22 b	4.6 b	0.33	13.94 b	1.37	1.46
Significance						
K	NS	*	**	NS	*	*
Cv	***	***	NS	***	NS	NS
K*Cv	NS	NS	NS	NS	NS	NS

^aFM = fresh matter.

^bMean value followed by different lower case letters in each column for each parameter did differ significantly.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

TA was influenced by K levels in the nutrient solution but not by the cultivars. By doubling K from 150 to 300 mg·L⁻¹, acidity increased by 14%. The highest K level did not induce any further increase (Table 1). The TSS/TA ratio was greater for 'Kabiria' than for 'SVR' and 'Esperanza' (Table 1); the analysis of orthogonal polynomial contrasts revealed a lower TSS/TA ratio with increasing K levels in the nutrient solution, showing a significant linear relationship ($P \leq 0.05$). It is widely recognized that potassium influences the maintenance of electroneutrality of organic acids in tomato fruits (Adams and Ho, 1993; Dorais et al., 2001; Petersen et al., 1998). A correct balance between sugar and acid contents is crucial for the processing industry (which requires precise guidelines to avoid product alteration problems during the storage phase) and also important for the fresh-market production industry because such ratio determines fruit tastiness (Auerswald et al., 1999).

Tocopherols were influenced both by genotype and K levels. In the three cultivars, the isoforms α and γ resulted in more than 94% of the total tocopherol content of tomato fruits, with γ -tocopherol levels not far from the α levels (Table 2). This is most likely the result of the presence of seeds in the tomato samples, because it is known that γ -tocopherol is the main form in tomato seeds (Seybold et al., 2004).

As far as α -tocopherol is concerned, when the K level was increased in the nutrient solution, a linear response was observed only in 'Kabiria', whereas 'SVR' and 'Esperanza' genotypes were not influenced by K levels (Fig. 1), possibly as a result of the lower water content of Kabiria fruits compared with the other two genotypes (Table 1).

Gamma-tocopherol showed the highest value when the intermediate K level was used (Table 2). It is worth underlining that, among the four forms, α -tocopherol has the highest vitamin E activity, being absorbed preferentially by the human body (Brigelius-Flohé and Traber, 1999). These results indi-

cate the possibility of enhancing the concentration of an important antioxidant such as α -tocopherol in tomato fruits by using increased levels of K in the nutrient solution. So far, there is very little information in the literature on the effects of different fertilizers on the antioxidant components of tomatoes (Toor et al., 2006). On the other hand, K plays a special role as an activator for several plant enzymes that catalyze a variety of metabolic activities (Suelter, 1985), and this could be the case for tocopherol biosynthesis, at least within an optimum range of application rates.

Thus, the increase of α -tocopherol in 'Kabiria' fruits could be the result of the K-induced enhancement of tocopherol biosynthesis in which the α form is known to be an end product and the γ form its precursor (Della Penna, 2005). On average, by doubling K from 150 to 300 mg·L⁻¹ in the nutrient solution, total tocopherols increased by 24%; a threefold K level (450 mg·L⁻¹) did not further increase the tocopherol content in 'Kabiria' but reduced the tocopherol content in 'SVR' (-25%) and 'Esperanza' (-12%) (Fig. 2). Beyond the effective K range of

Fig. 1. Alpha-tocopherol of tomato fruits in relation to different cultivars and potassium levels into nutrient solution. Vertical bars represent $\pm$ SE of mean values. FM = fresh matter.

Table 2. Tocopherol content of tomato fruits in relation to potassium levels and cultivar.

K level (mg·L ⁻¹)	Tocopherol (mg·kg ⁻¹ of FM ²)			
	α	γ	δ	Total
150	6.4 c ³	5.2 b	0.5	12.1 b
300	7.1 b	7.1 a	0.8	15.0 a
450	7.6 a	5.9 b	0.4	13.9 a
Cultivar				
Esperanza	5.2 b	4.7 b	0.4 b	10.3 c
Kabiria	9.9 a	8.0 a	0.6 ab	18.5 a
SVR	5.9 b	5.6 b	0.7 a	12.2 b
Significance				
K	**	*	NS	**
Cv	***	***	*	***
K*Cv	*	NS	NS	**

²FM = fresh matter.

³Mean value followed by different lower case letters in each column for each parameter did differ significantly.

ns, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, and 0.001 respectively.

Fig. 2. Total tocopherols of tomato fruits in relation to different cultivars and potassium levels into nutrient solution. Vertical bars represent $\pm$ SE of mean values.

application, a further increase was useless or seemed to inhibit the synthesis and/or accumulation of total tocopherols in all three tomato varieties tested.

As far as the genotype is concerned, variable tocopherol contents were observed. This is in agreement with Sgherri et al. (2007) and Fanasca et al. (2006) who found a remarkable variability with regard to tocopherol concentration of different tomato genotypes. When expressed on a fresh weight basis, the highest total tocopherol content was found in 'Kabiria' fruits (18.5 mg·kg⁻¹) compared with the other genotypes (12.2 and 10.3 mg·kg⁻¹ on average for 'SVR' and 'Esperanza'). Such genotype effect was enhanced when the total tocopherol content was expressed on a dry weight basis, being 303 mg·kg⁻¹ DM for 'Kabiria' fruits versus 235 and 224 mg·kg⁻¹ DM for 'SVR' and 'Esperanza', respectively. Because it is known that quality of tomato fruits also depends on their antioxidant contents (Dumas et al., 2003), and vitamin E is involved in the prevention of human chronic diseases (Traber and Sies, 1996), these findings together with the high lycopene contents characterizing hp cultivars (Serio et al., 2007) make 'Kabiria' an interesting variety from a nutritional perspective.

Conclusion

The total yield of tomato fruits was not influenced by K levels in the nutrient solution, whereas the influence of K on some organoleptic quality parameters such as reducing sugar and TA was confirmed, whereas vitamin E content of the fruits was significantly affected by differing K concentrations in the nutrient solution. Furthermore, among the analyzed genotypes, the hybrid (hp) Kabiria revealed the most interesting nutritional profile, having the highest vitamin E content with α -tocopherol levels reaching 11.64 mg·kg⁻¹ when plants received a nutrient solution containing 450 mg·L⁻¹ K.

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