Evolution of Nutritional Value of Two Tomato Genotypes Grown in Soilless Culture as Affected by Macrocation Proportions

Simone Fanasca, Giuseppe Colla¹, Youssef Rouphael, and Francesco Saccardo

Dipartimento di Produzione Vegetale, Università della Tuscia, via S. C. De Lellis snc, 01100 Viterbo, Italy

Giuseppe Maiani, Eugenia Venneria, and Elena Azzini

Istituto Nazionale di Ricerca per gli alimenti e la Nutrizione, 00178 Roma, Italy

Additional index words. *Lycopersicon esculentum*, lycopene, β -carotene, ripening, α -tocopherol

Abstract. A greenhouse experiment was carried out to determine the effect of cationic proportions (K, Ca, Mg) in the nutrient solution on carotenoids and α -tocopherol content at green–orange, orange, red, and intense-red ripening stages using a high-pigment tomato (*Lycopersicon esculentum* Mill.) cultivar hp ('Lunarossa') and a standard cultivar ('Corfù') grown in a soilless culture. The highest lycopene concentration was observed in the 'hp' cultivar at the red and intense-red ripening stages (3.0 mg/100 g fresh weight and 3.2 mg/100 g fresh weight respectively). In both cultivars, the concentration of β -carotene increased during the ripening stages, reaching the highest value (0.6 mg/100 g fresh weight) at the intense-red stage. The hp cultivar has guaranteed higher lycopene (average, 2.0 mg/100 g fresh weight vs. 1.7 mg/100 g fresh weight) and α -tocopherol contents (average, 1.2 mg/100 g fresh weight vs. 0.9 mg/100 g fresh weight) than those of the standard. In both cultivars, a high proportion of K in the nutrient solution increased antioxidant concentration (β -carotene and especially lycopene) during the red and intense-red ripening stages, followed by Mg. The lowest values were recorded for the Ca treatment. Lastly, a positive correlation was recorded between fruit tissue K and lycopene content, whereas a negative correlation was observed between fruit tissue Ca and lycopene content.

Tomato (*Lycopersicon esculentum* Mill.) is an important horticultural crop in the Mediterranean area, not only because of its economic importance, but also for the nutritional value of its fruits—mainly because it is an excellent source of folate K and antioxidant compounds (Beecher, 1997). The antioxidants are subdivided on the basis of their solubility in water in hydrophilic and lipophilic compounds. In tomato fruits, the carotenoids represent the most important class of lipophilic compounds. The carotenoids are

divided into the hydrocarbon carotenes, such as lycopene and β -carotene or xanthophylls typified by lutein (Bramley, 2002). The intake of antioxidant compounds in food is an important health-protecting factor. When taken daily in adequate amounts, carotenoids have been recognized as beneficial for prevention of widespread human diseases, including cancer and cardiovascular diseases (Castelao et al., 2004; Tapiero et al., 2004; Willcox et al., 2003).

During the ripening of tomato fruit color, texture, flavor, and aroma are changed as a result of a complex process during which ethylene activity plays a key role (Alexander and Grierson, 2002). The changes in color are attributed to a surge in lycopene of ≈ 500 -fold in the ripe fruit and the conversion of chloroplast to chromoplast (Fraser et al., 1994). Recent research (Arias et al., 2000; Kozukue and Friedman, 2003; Raffo et al., 2002) has shown the influence of ripening stage on antioxidant content of tomato fruits.

The antioxidant content of fresh tomatoes is affected by genotype, environmental conditions, cultural management, and postharvest factors (Dumas et al., 2003). Irrigation and nutrition management represent two

important preharvest factors influencing the biosynthesis of antioxidant compounds. Lycopene content of tomato fruits can be increased by reducing water availability into the root zone (Dumas et al., 2003). Another important agricultural factor is mineral nutrition. Paiva et al. (1998) showed a 29% decrease in lycopene concentration when the calcium level in the nutrient solution was increased from 0.2 to 20 mM. Moreover, Trudel and Ozbun (1971) have reported a 40% increase in lycopene concentration when the level of K in the nutrient solution was increased from 0 to 8 mM. Actually, a lack of information is available on the influence of Mg on biosynthesis of antioxidants in tomato. Moreover, a detailed assessment on the interaction effect of K, Ca, and Mg on the biosynthesis and accumulation of antioxidant compounds in tomato is still lacking.

Another important factor involved in the qualitative performance of tomato crop is the choice of cultivar (Dumas et al., 2003). Recently, breeding programs have given more attention to the cultivars that are referred to as 'hp'. These hybrids have shown a significant increment for lycopene content from 2.4 to 7-fold higher than those of commercial varieties (Lenucci et al., 2006).

The aim of the current study was to investigate the effect of cationic proportions (K, Ca, Mg) on the accumulation of water-insoluble antioxidants (carotenoids and α -tocopherol), using an hp tomato cultivar and a commercial tomato cultivar harvested at different ripening stages.

Materials and Methods

Plant material and growth conditions. The experiment was conducted in the spring–summer growing season in a 300-m² polyethylene greenhouse situated on the experimental farm of Tuscia Univ in central Italy (42°25'N, 12°08'E). Plants were grown under natural light conditions and automatic ventilation was provided when the air temperature in the greenhouse exceeded 25 °C. The temperature inside the greenhouse ranged from 15 to 36 °C. Treatments were arranged in a complete randomized block design with four replicates per treatment. Treatments were defined by a factorial combination of three nutrient solutions having different cationic proportions ($S_K = 0.68 \text{ K}/0.16 \text{ Ca}/0.16 \text{ Mg}$; $S_{Ca} = 0.16 \text{ K}/0.68 \text{ Ca}/0.16 \text{ Mg}$; $S_{Mg} = 0.16 \text{ K}/0.16 \text{ Ca}/0.68 \text{ Mg}$) and two unidentified growing round tomato cultivars: Corfù (standard cultivar; SAIS Seed Company, Cesena, Italy) and 'Lunarossa' (hp cultivar; Bergschenhock, the Netherlands). Each experimental unit consisted of three plants.

At the two true-leaf stage, tomato plants were transplanted (17 Mar.) in pots containing 3.8 L quartz sand. Plants were planted in rows 1.3 m apart, and the space between the plants within a row was 0.5 m. The distance between the centers of double rows was 1.9 m, resulting in a plant density of 2.1 plant/m².

Received for publication 23 May 2006. Accepted for publication 4 Aug. 2006.

This work was supported by the Italian Ministry of University and Research (MIUR-PRIN 2005), Project "Aspetti fisiologici e tecnologici della nutrizione minerale di piante ortive coltivate fuori suolo con sistemi a ciclo chiuso e ricadute sullo stato fitosanitario delle colture" (DM no. 287 del 23 febbraio 2005-Progetti di ricerca di interesse nazionale 2005).

We thank Dr. George W. Barbour for scientific language editing and Lara Palomba for technical assistance.

¹To whom reprint requests should be addressed; e-mail giucolla@unitus.it

Table 1. Mean effect of nutrient solution composition and cultivar on marketable yield, fruit mean weight, and number of tomato fruits.

Treatments	Marketable yield (kg/plant)	Mean fruit mass (g)	Fruit number (no./plant)
Nutrient solution			
S _K ²	3.4	134.4	24.6
S _{Ca}	5.6	121.5	46.4
S _{Mg}	4.1	131.6	30.9
Cultivar			
Corfù	5.0	142.7	35.7
Lunarossa	3.7	115.6	32.1
Significance			
Nutrient solution (S)	***	NS	***
Cultivar (C)	***	***	*
S × C	NS	NS	NS

²S_K, S_{Ca}, and S_{Mg} nutrient solution with a high proportion of K, Ca, and Mg respectively.

NS,*,***Nonsignificant or significant at $P < 0.05$ and 0.001 respectively.

Table 2. Color readings red (R) ±SE (in brackets) during the four ripening stages.

Ripening stage	Color readings					Chroma (C*)
	L*	a*	b*	a*/b*	Hue (H*)	
G-O	37.4 (0.85)	5.2 (0.10)	22.5 (0.37)	0.2 (0.01)	1.3 (0.01)	23.1 (0.37)
O	35.3 (0.98)	9.3 (1.91)	21.1 (0.75)	0.5 (0.10)	1.1 (0.01)	23.2 (0.54)
R	34.6 (0.22)	28.7 (1.74)	23.6 (1.45)	1.0 (0.25)	0.8 (0.05)	34.9 (1.36)
IR	33.7 (0.86)	30.2 (0.97)	23.0 (1.14)	1.3 (0.10)	0.7 (0.04)	37.3 (0.35)

Table 3. Analysis of variance of lycopene, β-carotene, lutein, and α-tocopherol content of tomato fruits.

Factor	Analysis of variance			
	Lycopene	β-carotene	Lutein	α-tocopherol
Nutrient solution (S)	***	*	NS	NS
Cultivar (C)	*	NS	NS	*
Ripening stage (R)	***	***	NS	NS
S × C	NS	NS	NS	NS
S × R	*	NS	NS	NS
C × R	*	NS	NS	NS
S × C × R	NS	NS	NS	NS

NS,*,***Nonsignificant or significant at $P < 0.05$ or 0.001 respectively.

Fig. 1. Mean effects of nutrient solution composition and ripening stage on lycopene content of tomato fruits. Different letters indicate significant differences according to the LSD test ($P = 0.05$). G-O, green–orange; IR, intense red; O, orange; R, red.

Nutrient solution management. In all nutrient solutions, the macroanion proportions were $0.67 \text{ NO}_3^- : 0.26 \text{ SO}_4^{2-} : 0.07 \text{ H}_2\text{PO}_4^-$, and the ratio of anions ($\text{NO}_3^- + \text{SO}_4^{2-} + \text{H}_2\text{PO}_4^-$) to cations ($\text{K}^+ + \text{Ca}^{2+} + \text{Mg}^{2+}$) was equal to one. The total macronutrients concentration was $42 \text{ meq}\cdot\text{L}^{-1}$. In all treatments, the concentrations of macroanions (proportion × total concentration) were $14.1 \text{ meq}\cdot\text{L}^{-1} \text{ NO}_3^-$, $5.5 \text{ meq}\cdot\text{L}^{-1} \text{ SO}_4^{2-}$, and $1.5 \text{ meq}\cdot\text{L}^{-1} \text{ H}_2\text{PO}_4^-$. The concentrations of macrocations were $14.2 \text{ meq}\cdot\text{L}^{-1} \text{ K}^+$, $3.4 \text{ meq}\cdot\text{L}^{-1} \text{ Ca}^{2+}$, and $3.4 \text{ meq}\cdot\text{L}^{-1} \text{ Mg}^{2+}$ for the S_K treatment; $3.4 \text{ meq}\cdot\text{L}^{-1} \text{ K}^+$, $14.2 \text{ meq}\cdot\text{L}^{-1} \text{ Ca}^{2+}$, and $3.4 \text{ meq}\cdot\text{L}^{-1} \text{ Mg}^{2+}$ for the S_{Ca} treatment; and $3.4 \text{ meq}\cdot\text{L}^{-1} \text{ K}^+$, $3.4 \text{ meq}\cdot\text{L}^{-1} \text{ Ca}^{2+}$, and $14.2 \text{ meq}\cdot\text{L}^{-1} \text{ Mg}^{2+}$ for the S_{Mg} treatment. Moreover, the micronutrient concentrations in all treatments were $40.0 \text{ }\mu\text{eq}\cdot\text{L}^{-1} \text{ Fe}$, $18.0 \text{ }\mu\text{eq}\cdot\text{L}^{-1} \text{ Mn}$, $3.0 \text{ }\mu\text{eq}\cdot\text{L}^{-1} \text{ Cu}$, $6.0 \text{ }\mu\text{eq}\cdot\text{L}^{-1} \text{ Zn}$, $60.0 \text{ }\mu\text{eq}\cdot\text{L}^{-1} \text{ B}$, and $1.8 \text{ }\mu\text{eq}\cdot\text{L}^{-1} \text{ Mo}$. The electrical conductivity and pH of the nutrient solutions were $2.0 \pm 0.2 \text{ dS}\cdot\text{m}^{-1}$ and 6.0 respectively. Demineralized water was used in the preparation of all nutrient solutions. The nutrient solution was pumped from an independent tank through a drip irrigation system with one emitter flow rate of $2 \text{ L}\cdot\text{h}^{-1}$. Irrigation scheduling was performed using electronic low-tension tensiometers (LT-Irrrometer, Riverside, Calif.) that permitted one to control irrigation on the basis of substrate matric potential (Norrie et al., 1994). Tensiometers were connected to an automatic irrigation controller that controlled the beginning of irrigation (5 kPa) and the end of irrigation (1 kPa), which corresponded to high and low tension set points for the major part of media (Kiehl et al., 1992). Three to 20 fertigation were applied per day, the watering time was of 1 to 3 min each. The timing of irrigation was increased to have 30% or more of the solution being drained from the pots.

Measurements and analysis. Fully ripe fruit harvest was started on 18 May and continued until the end of the experiment. The number of fruits, mean fruit mass, and marketable and unmarketable yields were recorded on three plants per plot. The experiment was ended on 17 July.

The fruits of the fourth truss were harvested and separated into four groups according to the ripening stages: green–orange (G-O, $\approx 30\%$ orange skin), orange (O, $\approx 100\%$ orange skin), red (R, 100% red skin), and intense red (IR, 10 d after the R stage). Three to five tomatoes per group of each plot were analyzed for color, carotenoids, and α-tocopherol. The chromatic coordinates (L^* , a^* , and b^*) were measured as described by McGuire (1992) by a tristimulus color analyzer (Minolta Chroma Meter CR-200, Minolta Camera Co. Ltd., Osaka, Japan). The chroma (C^*) and hue were also calculated according to the equations of Arias et al. (2000).

In the current study, the a^* -to- b^* ratio determined on the skin was considered as a reference parameter for the ripening stage, in accordance with several studies (Arias et al., 2000; Raffo et al., 2002). After the color measurements, fruits from each treatment

were homogenized in a Waring blender for 1 min. Tomato carotenoids and α -tocopherol were determined as described by Sharpless et al. (1999). Briefly, 50 μ L reconstituted extract was injected on a Waters Nova Pack C18 column (3.9 $\times$ 150 mm), 4 μ m, at a flow rate of 1 mL $\cdot$ min $^{-1}$. The extracts were analyzed using a Perkins–Elmer ISS 200 series HPLC system. The peaks were detected with a variable spectrophotometric detector (Perkins–Elmer LC-95, Norwalk, Conn.) connected to a personal computer PeNelson model 1020 (Perkins–Elmer). The detection wavelengths were 450 nm and 292 nm respectively for carotenoids and α -tocopherol.

Fruits at the R ripening stage were dried in a forced-air oven at 80 $^{\circ}$ C for 72 h. Dry fruit was ground in a Wiley mill to pass through a 20-mesh screen and was analyzed for the elements K and Ca. These elements were determined by dry ashing at 400 $^{\circ}$ C for 24 h, dissolving the ash in HCl 1:25 v/v, and assaying the supernatant using an inductively coupled plasma emission spectrophotometer (ICP Iris; Thermo Optek, Milano, Italy) (Karla, 1998).

Statistical analysis. All data were statistically analyzed by analysis of variance using the SPSS software package (SPSS 10 for Windows, 2001). The LSD test was performed at $P = 0.05$ on each of the significant variables measured. Regression analysis was conducted to identify the relationships between the measured parameters (lycopene, Ca, and K concentration).

Results and Discussion

Fruit yield components. Marketable yield and fruit number were significantly affected by nutrient solution composition and cultivar, but not by their interaction. The marketable mean fruit mass was significantly influenced by cultivar and not by nutrient solution composition, with no nutrient solution composition $\times$ cultivar interaction (Table 1). Averaged across the cultivar, the highest marketable yield was observed in the nutrient solution containing the high proportion of Ca (S_{Ca}), followed by the S_{Mg} and S_K treatments. The lower marketable yield in S_K and S_{Mg} compared with the S_{Ca} treatments was the result of a lower number of marketable fruit per plant. Averaged across the nutrient solution composition, the marketable yield was 26% higher in ‘Corfù’ than in ‘Lunarossa’ as a result of an increase in fruit mean mass and number of fruit per plant (Table 1).

Fruit color. The lightness factor, L^* , decreased during the ripening stages. The decrease in L^* with ripening reflects the darkening of the tomatoes with carotenoid synthesis and the loss of greenness (Arias et al., 2000). The a^* value increased from 5.2 to 30.2 in response to the synthesis of lycopene and the depletion of chlorophyll, which represents the color change from G to R (Table 2). The b^* value increased through the second (O) and third (R) ripening stages of the tomatoes and then became stable, reflecting the synthesis of β -carotene (the

second most important carotenoid in tomatoes) and its subsequent masking resulting from the increase in lycopene concentration. Tomatoes picked at four different ripening stages showed a^*/b^* values significantly increasing from 0.2 to 1.3, showing an inverse linear relationship ($r = -0.84^{**}$) with respect to L^* . Finally, the hue (H^*) decreased from 1.3 to 0.7, whereas an opposite trend was recorded for chroma (C^*) (Table 1).

Carotenoids and α -tocopherol. Lycopene content was significantly affected by nutrient

solution composition, cultivar, ripening stage, and by the cultivar $\times$ ripening stage and nutrient solution $\times$ ripening interactions, whereas only nutrient solution composition and ripening stage affected β -carotene content (Table 3). No significant differences were recorded for lutein in all treatments (average, 0.13 mg/100 g fresh weight). Moreover, the α -tocopherol content was highly influenced by cultivar but not by nutrient solution composition and ripening stage and their interactions (Table 3), with the higher

Fig. 2. Relationship between fruit K concentration and lycopene content at the red stage in Lunarossa and Corfù tomato cultivars.

Fig. 3. Relationship between fruit Ca concentration and lycopene content at the red stage in Lunarossa and Corfù tomato cultivars.

Fig. 4. Mean effects of cultivar and ripening stage on lycopene content of tomato fruits. Different letters indicate significant differences according to the LSD test ($P = 0.05$).

Fig. 5. Mean effects of ripening stage on β-carotene content of tomato fruits from both cultivars. Different letters indicate significant differences according to the LSD test ($P = 0.05$).

value recorded in 'Lunarossa' than in 'Corfu' (average, 1.2 mg/100 g vs. 0.9 mg/100 g fresh weight).

In the current experiment, the lycopene concentration increased during the ripening stage, with a significant increase between the first two ripening stages (G-O and O) and the R stage, reflecting lycopene biosynthesis (Fig. 1). The development of lycopene during the ripening of tomatoes coincides with earlier findings (Arias et al., 2000; Raffo et al., 2002). When averaged across cultivars, no significant differences were observed among treatments during the first two stages (Fig. 1). The highest lycopene concentration

was recorded at the R and IR stages on plants grown in nutrient solution with a high proportion of K followed by Mg, whereas the lowest values was recorded for the S_{Ca} treatment. Lastly, the current data showed a linear relationship between lycopene content and K concentration (Fig. 2), whereas an inverse linear relationship existed between lycopene and Ca concentrations (Fig. 3). The positive effect of K on lycopene concentration has been reported previously by Trudel and Ozbun (1971). K may be involved in the process of lycopene biosynthesis through its influence on the activity of enzymes that regulate carbohydrate metabolism, such as

pyruvate kinase and phosphofructokinase as well as precursors of IPP (pyruvate and glyceraldehyde 3-phosphate). Moreover, in the current experiment, accumulation of K in fruits was responsible for increasing the lycopene concentration for both the Lunarossa and Corfu cultivars. The negative effect of Ca concentration recorded in the current experiment confirm the data reported by Paiva et al. (1998), showing that an increase in Ca concentration of the nutrient solution results in a decrease in lycopene content as a result of the antagonism between Ca and K, or the possible Ca influence on ethylene biosynthesis.

Averaged across nutrient solution composition, the hp cultivar had a higher lycopene level in the R and IR ripening stages compared with the Corfu cultivar, whereas the lowest values were recorded during the first two ripening stages with no significant differences among cultivars (Fig. 4).

The current results are in line with those reported by Lenucci et al. (2006), who found lycopene accumulation in 'hp' hybrids up to sevenfold more than standard hybrids under field conditions. However, the lycopene levels detected in our fruits were relatively low when compared with values of different typologies (cherry, cluster, elongated, and salad) of tomato fruits (Leonardi et al., 2000). The low lycopene content reported in the current experiment could be the result of climatic conditions inside the greenhouse, especially air temperature, which exceeded 30 °C during the ripening period, leading to a reduction in lycopene biosynthesis (Robertson et al., 1995).

The β-carotene, lutein, and α-tocopherol contents observed during the current experiment are in line with those reported by Abushita et al. (2000). Temperatures higher than 32 °C did not reduce the β-carotene content, because higher temperatures are required for its biosynthesis (Dumas et al., 2003). Moreover the high temperatures registered in the current experiment did not decrease the lutein and α-tocopherol contents.

With regard to the other important lipophilic antioxidant, β-carotene, the highest values were recorded on plants grown in nutrient solution with a high proportion of K (average, 0.53 mg/100 g fresh weight) followed by Mg (average, 0.49 mg/100 g fresh weight), whereas the lowest value was recorded for the S_{Ca} treatment (average, 0.43 mg/100 g fresh weight). β-carotene increased during ripening (Fig. 5), and its content during the IR stage expressed on a fresh weight basis was 0.65 mg/100 g. Contradictory results concerning the accumulation rate during ripening have been reported. In some studies β-carotene concentration increased throughout ripening (Abushita et al., 2000; Giovanelli et al., 1999), whereas in other studies the maximum level was reached before full ripening stage (Davies and Hobson, 1981; Koskitalo and Omrod, 1972). These differences have been attributed to different growing conditions and cultivars

(De Pascale et al., 2001; Leonardi et al., 2000; Petersen et al., 1998).

To summarize, it can be concluded that during ripening, an improvement of quality attributes related to consumer acceptance and nutritional value can occur. In addition, our study showed that a high proportion of K in the nutrient solution increased antioxidant concentration (especially lycopene) during the last two ripening stages [red (R) and intense red (IR)], whereas a high proportion of Ca decreased tomato fruit quality but improved tomato fruit yield. Furthermore, the tomato high-pigment hybrid has guaranteed an antioxidant concentration higher than that of the standard hybrid, but with lower marketable yield.

Lastly, growers can improve tomato fruit quality (antioxidant content) using an hp hybrid and increasing the proportions of K up to 0.68 of total macrocations in the nutrient solution.

Literature Cited

- Abushita, A.A., E.A. Hebshi, H.G. Daood, and P.A. Biacs. 2000. Change in carotenoids and antioxidant vitamins in tomato as a function of varietal and technological factors. *J. Agr. Food Chem.* 48:2075–2081.
- Alexander, L. and D. Grierson. 2002. Ethylene biosynthesis and action in tomato: A model for climacteric fruit ripening. *J. Exp. Bot.* 53:2039–2055.
- Arias, R., T.C. Lee, L. Logendra, and H. Janes. 2000. Correlation of lycopene measured by HPLC with the L*, a*, b* color readings of a hydroponic tomato and the relationship of maturity with color and lycopene content. *J. Agr. Food Chem.* 48:1697–1702.
- Beecher, G.R. 1997. Nutrient content of tomatoes and tomato products. *Proc. Soc. Exp. Biol. Med.* 218:98–100.
- Bramley, P.M. 2002. Regulation of carotenoids formation during tomato fruit ripening and development. *J. Exp. Bot.* 53:2107–2113.
- Castelao, J.E., J.M. Yuan, M. Gago-Dominguez, P.L. Skipper, S.R. Tannenbaum, K.K. Chan, M.A. Watson, D.A. Bell, G.A. Coetzee, R.K. Ross, and M.C. Yu. 2004. Carotenoids/vitamin C and smoking-related bladder cancer. *Int. J. Cancer.* 110:417–423.
- Davies, J.N. and G.E. Hobson. 1981. The constituents of tomato fruit. The influence of environment, nutrition, and genotype. *Crit. Rev. Food Sci. Nutr.* 15:205–280.
- De Pascale, S., A. Maggio, V. Fogliano, P. Ambrosino, and A. Ritieni. 2001. Irrigation with saline water improves carotenoids content and antioxidant activity of tomato. *J. Hort. Sci. Biotechnol.* 76:447–453.
- Dumas, Y., M. Dado, G. Di Lucca, and P. Grolier. 2003. Effects of environmental factors and agricultural techniques on antioxidant content of tomatoes. *J. Sci. Food Agr.* 83:369–382.
- Fraser, P.D., M.R. Truesdale, C.R. Bird, W. Schuch, and P.M. Bramley. 1994. Carotenoid biosynthesis during the tomato fruit development. Evidence for tissue-specific gene expression. *Plant Physiol.* 105:405–413.
- Giovannelli, G., V. Lavelle, C. Peri, and S. Nobili. 1999. Variation in antioxidant components of tomato during vine and post-harvest ripening. *J. Sci. Food Agr.* 79:1583–1588.
- Karla, Y.P. 1998. Handbook of reference methods for plant analysis, p. 165–170. CRC Press Inc., Boca Raton, Fla.
- Kiehl, P.A., J.H. Lieth, and D.W. Burger. 1992. Growth response of chrysanthemum to various container medium moisture tension levels. *J. Amer. Soc. Hort. Sci.* 117:224–229.
- Koskitalo, D.N. and D.P. Omrod. 1972. Effect of sub-optimal ripening temperatures on the color quality and pigment composition of tomato fruit. *J. Food Sci.* 37:56–62.
- Kozukue, N. and M. Friedman. 2003. Tomatine, chlorophyll, β -carotene and lycopene content in tomatoes during growth and maturation. *J. Sci. Food Agr.* 83:195–200.
- Lenucci, M.S., D. Cadinu, M. Taurino, G. Piro, and G. Dalessandro. 2006. Antioxidant composition in cherry and high-pigment tomato cultivars. *J. Agr. Food Chem.* 54:2606–2613.
- Leonardi, C., P. Ambrosino, F. Esposito, and V. Fogliano. 2000. Antioxidative activity and carotenoid and tomatine contents in different typologies of fresh consumption tomatoes. *J. Agr. Food Chem.* 48:4723–4727.
- McGuire, R.G. 1992. Reporting objective color measurements. *HortScience* 27:1254–1255.
- Norrie, J., M.E.D. Graham, and A. Gosselin. 1994. Potential evapotranspiration as a means of predicting irrigation timing in greenhouse tomatoes grown in peat bags. *J. Amer. Soc. Hort. Sci.* 119:163–168.
- Paiva, E.A.S., R.A. Sampaio, and H.E.P. Martinez. 1998. Composition and quality of tomato fruit cultivated in nutrient solutions containing different calcium concentrations. *J. Plant Nutr.* 21:2653–2661.
- Petersen, K.K., J. Willumsen, and K. Kaack. 1998. Composition and taste of tomatoes as affected by increased salinity and different salinity sources. *J. Hort. Sci. Biotechnol.* 73: 205–215.
- Raffo, A., C. Leonardi, V. Fogliano, P. Ambrosino, M. Salucci, L. Gennaro, R. Bugianesi, F. Giuffrida, and G. Quaglia. 2002. Nutritional value of cherry tomatoes (*Lycopersicon esculentum* cv. Naomi F1) harvested at different ripening stages. *J. Agr. Food Chem.* 50:6550–6556.
- Robertson, G.H., N.E. Mahoney, N. Goodman, and A.E. Pavlath. 1995. Regulation of lycopene formation in cell suspension culture of VFNT tomato (*Lycopersicon esculentum*) by CPTA, growth regulators, sucrose, and temperature. *J. Exp. Bot.* 46:667–673.
- Sharpless, K.A., M. Arce-Osuna, J.B. Thoma, and M.L. Gill. 1999. Value assignment of retinyl palmitate, tocopherol and carotenoid concentrations in standard reference material 2383 (baby food composite). *J. AOAC* 82: 288–296.
- Tapiero, H., D.M. Townsend, and K.D. Tew. 2004. The role of carotenoids in the prevention of human pathologies. *Biomed. Pharmacother.* 58:100–110.
- Trudel, M.J. and J.L. Ozbun. 1971. Influence of potassium on carotenoid content of tomato fruit. *J. Am. Soc. Hort. Sci.* 96:763–765.
- Willcox, J.K., G.L. Catignani, and S. Lazarus. 2003. Tomatoes and cardiovascular health. *Crit. Rev. Food Sci. Nutr.* 43:1–18.