Cultivar, Maturity, and Heat Treatment on Lycopene Content in Tomatoes

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ABSTRACT: Using high performance liquid chromatography, tomato cultivars which contain the Crimson gene (og) were usually found to have higher lycopene content (5086 to 5786 μg/100 g fresh weight) than those cultivars lacking the gene (2622 to 4318 μg/100 g fresh weight). A comparison of the color readings taken from tomatoes at the equatorial region with those of the homogenate prepared from the same region showed that the hue of tomato homogenate was a better indicator of lycopene content than tomato surface hue. The tomatoes' lycopene content was not affected by ethylene treatment or cooking for 4, 8, and 16 min at 100 °C.

Key Words: tomato, lycopene, Crimson gene, maturity stage, cooking

Introduction

LYCOPENE IS A CAROTENOID FOUND IN fruits and vegetables and is responsible for the redness in tomato (*Lycopersicon esculentum* Mill.), red pepper, and red grapefruit (Hakala and Heinonen 1994; Sadler and others 1990). The function of lycopene is to harvest light and protect the plant from photooxidative damage (Conn and others 1991). During normal aerobic cellular metabolism, highly reactive oxygen species are produced and lycopene can act as an antioxidant in reacting with these species which can otherwise cause cell damage. Lycopene has eleven conjugated double bonds which withstand attack from peroxy radicals, forming inactive products resulting in cell stabilization (Chew 1995). Singlet oxygen is quenched by lycopene at a rate of almost twice that of β-carotene (Conn and others 1991; Devasagayam and others 1992).

Heating or cooking tomatoes or tomato products may increase the bioavailability of lycopene. It has been reported that the consumption of unheated tomato juice did not increase serum lycopene concentrations (Stahl and Sies 1992). During processing, the thermally induced rupture of cell walls and the release of lycopene contributes to the increased lycopene content in processed tomato products (Stahl and Sies 1992). Water loss during processing also contributes to higher concentrations of lycopene in processed tomato products.

The quantity of lycopene in tomatoes has been reported to be dependent upon the ripeness of the fruit at the time of harvesting (Sadler and others 1990). As tomatoes develop from immature green to ripe, the increase in carotenoid content is seen by the change in pigmentation (Fraser and others 1994). The change in pigment is caused by the increase in lycopene content within the plastids. The lycopene contents for immature green (surface color is completely green and no jelly-like material is present in any of the locules), mature green (surface color is completely green and jelly-like matrix in all locules), breaker (not more than 10% of surface color is pink or red), firm red (more than 90% of surface color shows red), and overripe tomatoes (rotting) are reported as follows: 25, 10, 370, 4600, and 7050 μg/100 g, respectively (Fraser and others 1994).

In addition to the confirmation that lycopene content changes during tomato development and maturation, this study compares the lycopene content of various cultivars, as well as lycopene content of stewed tomatoes prepared from raw tomatoes of the various cultivars.

Results and Discussion

Effect of Cultivar Variation on Tomato Lycopene Content

Crimson gene tomatoes, such as 'Suncoast' (*og*) and FL7692D (*og*), were higher in lycopene content than most other varieties (Table 1). However, the 'Equinox' variety was comparable to the Crimson gene tomatoes although it lacks this gene. The rin variety, 97E212S (rin/+), had the least amount of lycopene. Therefore, high lycopene content in 'Equinox' cannot be attributed to this gene. The crimson gene (*og*) tomato trait is of interest because it is suspected to elicit a higher lycopene content. This gene may open up the lycopene formation pathway, thereby producing a tomato with high lycopene content (Thompson and others 1964).

The L, a, b values were measured for both the surface and a homogenate of the tomato slices (Table 1). The hue value was calculated by taking the $\tan^{-1}(b/a)$. A low positive hue value indicates a redder color. From this study, the correlation of surface hue value and lycopene content, −0.71, was not as good as the correlation for the homogenate, −0.85. Thus, the hue value of the tomato puree is a better indicator of lycopene content than the outside surface of the tomatoes.

FL7692B and FL7692D (*og*) had lower moisture contents and significantly higher soluble solids contents than most varieties tested, which is 5.00. 'Solar Set' tomatoes had the lowest pH value, 3.9 (Table 1). The 'Agriset' and 'Equinox' varieties had

Table 1—Lycopene content, hue, pH, soluble solids content, and % citric acid of eight red ripe tomato cultivars

Cultivar	Lycopene content μg/100 g	Surface hue $\tan^{-1}(b/a)$	Homogenate hue $\tan^{-1}(b/a)$	pH	Soluble solids (%)	Citric acid (%)
Agriset	4318^{c} (169)	0.42^{de} (0.05)	0.47^{cd} (0.02)	4.21^{bc} (0.05)	4.68^{abc} (0.21)	0.57^{a} (0.03)
FL7692B	4159^{c} (231)	0.48^{b} (0.06)	0.46^{d} (0.02)	4.25^{ab} (0.09)	5.00^{a} (0.38)	0.44^{c} (0.01)
FL7692D (*og*)	5786^{a} (512)	0.43^{de} (0.04)	0.45^{d} (0.01)	4.34^{a} (0.06)	5.00^{a} (0.20)	0.38^{d} (0.05)
Suncoast (*og*)	5068^{b} (512)	0.46^{c} (0.04)	0.45^{d} (0.01)	4.19^{bc} (0.02)	4.23^{d} (0.15)	0.50^{b} (0.04)
Equinox	5550^{a} (257)	0.41^{e} (0.04)	0.47^{d} (0.01)	4.09^{d} (0.10)	4.73^{ab} (0.15)	0.57^{a} (0.03)
97E212S (rin/+)	2622^{d} (411)	0.50^{a} (0.08)	0.58^{a} (0.02)	4.13^{cd} (0.08)	4.38^{cd} (0.19)	0.45^{b} (0.02)
FL7655	4282^{c} (703)	0.47^{bc} (0.05)	0.50^{b} (0.01)	4.16^{cd} (0.06)	4.18^{d} (0.21)	0.53^{b} (0.04)
Solar Set	4155^{c} (536)	0.43^{d} (0.05)	0.49^{bc} (0.02)	3.91^{e} (0.04)	4.45^{bcd} (0.06)	0.53^{ab} (0.01)

$^{a-f}$ Means (standard deviation) within a column followed by different letters are significantly different ($p<0.05$).

significantly higher citric acid content: 0.57% for both varieties.

Effect of Maturity Stage and Cultivar Variation on Tomato Lycopene Content

Mature green tomatoes had a negative hue value on day 0 indicating a greener color. As the tomatoes began turning from breaker to red, the hue value increased to over 1.0, and then decreased as the redness increased.

The four cultivars of tomatoes harvested at mature green stage showed no difference in lycopene content on day 0 (Table 2). However, the Crimson gene (*og*) tomatoes, 'Suncoast' and FL7692D (*og*), harvested at the breaker stage (day 0), had significantly higher lycopene contents, 1210 and 1511 μg/100 g respectively, than the 'Agriset' and 'Solar Set' varieties. The two Crimson gene (*og*) red ripe tomatoes analyzed on day 0 were also the highest in lycopene content. However, only FL7692D (*og*) was significantly higher in lycopene content, 5560 μg/100 g, than the other varieties. These results are similar to those shown in Table 1.

Tomatoes harvested at the breaker stage and stored at room temperature for 6 days had significantly higher lycopene content than their cultivar counterparts harvested at mature green stage, treated with ethylene, and stored for 6 days (Table 2). On day 6, tomatoes treated with ethylene were turning pink while the tomatoes harvested at breaker stage were at light red to red ripening stage. Although 'Suncoast' (*og*) tomatoes had the highest lycopene content harvested at both the green and breaker stages, the other Crimson gene-containing tomato cultivar, FL7692D, did not differ significantly from the two non-Crimson gene tomatoes in lycopene content.

A comparison of the 9-d storage samples among the four varieties showed that only 'Suncoast' (*og*) treated with ethylene had a significantly lower lycopene content, 4847 μg/100 g, than the same variety harvested at breaker stage, 6178 μg/100 g (Table 2). Among those tomatoes that were treated with ethylene, only 'Agriset' had a significantly lower lycopene content, 3744 μg/100 g. Among the tomatoes that were harvested at breaker stage, 'Agriset' also had significantly lower lycopene content, 3174 μg/100 g, while the 'Suncoast' (*og*) had the significantly highest, 6178 μg/100 g (Table 2). For the 9-day samples, tomatoes harvested at the breaker stage were at the red ripeness stage while tomatoes treated with ethylene were at the light red or red ripe stage.

For 12-d storage tomatoes, 'Agriset' was the only variety to show significantly lower lycopene content, 2564 μg/100g, among ethylene treated tomatoes and its breaker stage counterparts. Among the ethylene treated tomatoes, the 'Agriset' variety had a significantly lower lycopene content (Table 2). There is no significant difference in lycopene content among tomato varieties harvested at breaker stage and stored at room temperature for 12 days (Table 2).

When comparing day 12 tomatoes with those harvested at the red ripe stage, 'Suncoast' (*og*) and 'Solar Set' varieties showed no differences in lycopene content (Table 2). All tomatoes were at the red ripeness stage on day 12. The FL7692D (*og*) variety showed no significant difference in lycopene content between the ethylene treated and breaker stage day 12 tomatoes. However, the FL7692D (*og*) harvested at red ripe stage had a significantly higher lycopene content than the day 12 breaker and ethylene treated tomatoes (Table 2). The 'Agriset' variety showed no difference in lycopene content between tomatoes harvested at red ripe and those that were harvested at breaker stage and allowed to ripen. However, the lycopene content of ethylene treated, day 12 tomatoes was significantly lower than their breaker and red ripe counterparts.

The lycopene content for stored tomatoes over 9 d was followed. For breaker tomatoes, storing 6 d resulted in the highest lycopene content (Table 2). For tomatoes harvested at mature green, treated with ethylene and stored, the highest lycopene content occurred on day 9. These respective storage days were compared with day 0 of tomatoes harvested red ripe. Among varieties, only the day 6 'Solar Set' harvested at breaker stage (significantly higher lycopene content) and day 9 of the 'Agriset' harvested at mature green and then treated with ethylene (significantly lower lycopene content) were significantly different from the other varieties. Tomatoes on these respective days were mostly at the red ripeness stage. Tomatoes containing the Crimson gene (*og*) were higher in lycopene content across all varieties. However, these values were not always significantly different.

Evaluation of the hue value across varieties and maturity stages was not always indicative of lycopene content. For example, on day 12 of storage, the ethylene treated 'Suncoast' (*og*) variety had the reddest hue value, while its lycopene content was not significantly different from the 'Solar Set' and FL7692D (*og*) varieties. Surface hue was not a good indicator of lycopene content in this study. The 'Agriset' and 'Suncoast' (*og*) varieties had the lowest hue values in the breaker tomatoes, yet the lycopene content of the 'Agriset' was significantly lower than all the other tomatoes harvested at the breaker stage.

The pH value generally increased as the fruits ripened while the soluble solids content and percent citric acid showed no clear trends (data not shown). The correlation coefficient for surface hue value and lycopene content for mature green tomatoes (day 0) was −0.29 while for homogenate hue value and lycopene content, the correlation coefficient was −0.93 (Tables 2 and 3). For breaker and red ripe tomatoes, the correlation coefficient for surface hue value and lycopene content was −0.62 while for homogenate hue value and lycopene content, the correlation coefficient was −0.83 (Tables 2 and 3). Thus, the homogenate hue value is a better indicator of lycopene content than surface hue.

Effect of Cooking on Lycopene Content

The pH of fresh tissue from the tomato varieties, 'Agriset', 'Solar Set', FL7765 (og),

Table 2—Lycopene content (μg/100 g) of various tomato cultivars on days 0 ,6 ,9, and 12 at mature green, breaker, and red ripe stages

Cultivar-maturity stage	Day 0	Day 6	Day 9	Day 12
Agriset				
green	8 (11)	1598^{d} (308)	3744^{cd} (809)	2564^{f} (349)
breaker	942^{b} (415)	4574^{b} (1030)	3174^{d} (854)	4276^{bcde} (1152)
red	4154^{c} (856)	ND	ND	ND
Solar Set				
green	7 (5)	2502^{cd} (552)	4803^{b} (602)	3638^{def} (620)
breaker	1084^{b} (321)	5636^{a} (1008)	4267^{bc} (797)	4489^{abcde} (1380)
red	4419^{bc} (742)	ND	ND	ND
Suncoast (*og*)				
green	8 (9)	3326^{c} (323)	4847^{b} (1786)	4257^{bcde} (842)
breaker	1210^{ab} (218)	6207^{a} (1807)	6178^{a} (678)	4571^{abcde} (1694)
red	5274^{ab} (998)	ND	ND	ND
FL7692D (*og*)				
green	7 (6)	2015^{d} (362)	4528^{bc} (630)	3699^{cdef} (1036)
breaker	1511^{a} (216)	4589^{b} (917)	4616^{bc} (784)	3077^{de} (1148)
red	5560^{a} (597)	ND	ND	ND

[a-f] The day 0 samples of the four varieties were compared at each maturity stage within the column, while both maturity stages of the day 6, day 9, and day 12 samples were compared within the column. Means (standard deviation) followed by different letters are significantly different ($p < 0.05$).

Table 3—Hue values of surface equatorial region and homogenate of various tomato cultivars on days 0, 6, 9, and 12 at mature green, breaker, and red ripe stages

Cultivar	Surface hue day 0	Homogenate hue day 0	Surface hue day 6	Homogenate hue day 6	Surface hue day 9	Homogenate hue day 9	Surface hue day 12	Homogenate hue day 12
Agriset								
green	-1.04^{d} (0.93)	-2.39^{e} (0.74)	0.42^{ab} (0.14)	1.15^{a} (0.13)	0.44^{a} (0.08)	0.83^{a} (0.04)	0.40^{a} (0.05)	0.66^{a} (0.03)
breaker	0.66^{ab} (0.26)	1.45^{a} (0.08)	0.37^{bc} (0.05)	0.68^{c} (0.03)	0.35^{c} (0.05)	0.70^{bcd} (0.05)	0.33^{c} (0.05)	0.63^{a} (0.03)
red	0.44^{ab} (0.04)	0.60^{d} (0.02)	ND	ND	ND	ND	ND	ND
Solar Set								
green	-0.69^{c} (1.25)	-3.23^{e} (0.17)	0.40^{bc} (0.11)	0.87^{b} (0.08)	0.41^{ab} (0.07)	0.76^{b} (0.05)	0.36^{bc} (0.03)	0.62^{a} (0.02)
breaker	0.64^{ab} (0.22)	1.37^{a} (0.18)	0.37^{c} (0.03)	0.62^{cd} (0.01)	0.34^{c} (0.04)	0.67^{cd} (0.03)	0.33^{c} (0.05)	0.62^{a} (0.02)
red	0.41^{b} (0.03)	0.58^{d} (0.03)	ND	ND	ND	ND	ND	ND
Suncoast(*og*)								
green	-1.35^{e} (0.07)	-2.88^{e} (0.12)	0.46^{a} (0.09)	0.62^{c} (0.02)	0.38^{b} (0.06)	0.61^{e} (0.03)	0.36^{bc} (0.03)	0.52^{b} (0.02)
breaker	0.73^{a} (0.31)	1.23^{b} (0.10)	0.39^{bc} (0.05)	0.54^{d} (0.04)	0.39^{ab} (0.08)	0.59^{e} (0.05)	0.39^{ab} (0.07)	0.65^{a} (0.07)
red	0.45^{ab} (0.05)	0.54^{d} (0.02)	ND	ND	ND	ND	ND	ND
FL7692D(*og*)								
green	-1.38^{e} (0.07)	-3.08^{e} (0.16)	0.46^{a} (0.10)	0.88^{b} (0.15)	0.41^{ab} (0.05)	0.74^{bc} (0.04)	0.40^{a} (0.05)	0.61^{a} (0.02)
breaker	0.67^{ab} (0.25)	1.05^{c} (0.12)	0.36^{c} (0.04)	0.65^{c} (0.06)	0.41^{ab} (0.07)	0.64^{de} (0.02)	0.36^{bc} (0.06)	0.64^{a} (0.04)
red	0.45^{ab} (0.05)	0.56^{d} (0.02)	ND	ND	ND	ND	ND	ND

[a-f] Means(standard deviation) within a column followed by different letters are significantly different ($p < 0.05$).

Table 4—Lycopene content at various cooking times at 100°C and hue values of the surface equatorial regions and tomato homogenates

Cultivar	Lycopene content μg/100 g at cooking time			
	0 min	4 min	8 min	16 min
Agriset	3027^{f} (1014)	2797^{f} (147)	4044^{e} (399)	2894^{f} (717)
Solar Set	4323^{e} (1351)	4478^{e} (1177)	4756^{de} (650)	4601^{e} (980)
FL7765 (*og*)	6710^{abc} (1571)	6111^{abc} (1096)	7194^{a} (1214)	6993^{ab} (1067)
FL7655	5712^{cd} (1196)	5717^{cd} (751)	6613^{abc} (759)	6006^{bc} (1073)

[a-f] Means (standard deviation) within columns followed by different letters are significantly different ($p < 0.05$).

and FL7655 did not differ significantly from one another (data not shown). The percent citric acid of FL7765 (*og*) cultivar was the only variety to differ significantly, 0.37 (data not shown). The soluble solids content of each variety was not significantly different except for the FL7655 cultivar, 4.4. The soluble solids content for this variety was a little lower than the other tomato varieties (data not shown). The water content of the tomatoes, about 95% before and after cooking, was not significantly different (data not shown).

The cooked and uncooked samples did not significantly differ in lycopene content (Table 4) except for the 8 minute cooking time for 'Agriset', which was significantly higher than its 4 and 16 min cooking times. However, it appeared there was a trend of higher lycopene content for the cooked tomatoes. The uncooked Crimson gene tomato, FL7765 (*og*), was significantly higher in lycopene content than the other varieties. The plum type, FL7655 was also high in lycopene content. The 'Solar Set' lycopene content was lower than the previous two cultivars, while 'Agriset' was the lowest of all varieties. The hue values at the equatorial surface region of the tomatoes did not significantly differ from one another (Table 4). However, the homogenate hue value of the Crimson gene (*og*) tomato was the lowest, indicating the reddest color. This tomato also had the highest lycopene content. The 'Agriset' variety had the highest hue value (least red) and the lowest lycopene content. The hue value of the tomato homogenate correlated well with lycopene content (correlation coefficient = −0.93) and the surface hue value of the tomatoes did not correlate well with lycopene content (correlation coefficient = −0.26).

In general, the tomatoes with the Crimson gene (*og*), were among the highest in lycopene content; ethylene treatment of tomatoes did not have a significant effect on lycopene content; and there was not a significant difference in lycopene content among cooked and uncooked tomatoes. However, cooked tomatoes generally had a higher lycopene content than uncooked. The hue value of the tomato homogenate was a better indicator of lycopene content than the surface hue value.

Materials and Methods

Effect of Cultivar Variation on Tomato Lycopene Content

Eight varieties of tomatoes were harvested on June 2, 1997 at the red ripe stage from the Gulf Coast Research Center, University of Florida at Bradenton, Fla., U.S.A., courtesy of Dr. John Scott and identified as: 'Agriset', 7692B, 'Suncoast' (containing crimson gene (*og*)), FL7692D (*og*), 'Equinox', FL7659, 97E212S (rin/+), and 'Solar Set'. Three color readings were taken from each tomato at the equatorial region using a Minolta Chromameter CR-200b (Ramsey, N.J.). Each tomato variety was divided into four groups, each group consisting of 5 tomatoes. Tomato homogenates were prepared by pooling the 1 cm slice from the equatorial region of each of the five tomatoes of the same variety, weighing, and homogenizing in a 400 mL glass jar. This was characterized as a group.

After the pH was measured using a Corning pH-30 Sensor (Corning, N.Y., U.S.A.), each group was placed in a Nalgene 250 mL amber plastic bottle for storage at −20 °C. Before storing, 20 g from each group was weighed and centrifuged for 10 min at 4700 rpm at room temperature. The supernatant was decanted. PH was measured and titratable acidity was measured by titrating to an end point of 8.1-8.2 with 0.1 N NaOH (Mencarelli and Saltveit 1988). The soluble solids content wasmeasured using a Leica Abbe Mark II Refractometer (Buffalo, N.Y., U.S.A.). The remaining homo-

genate samples were flushed with nitrogen gas, capped, and stored at −20 °C.

Lycopene Extraction

Prior to each extraction, the frozen homogenate samples were thawed under running water for 20 min. Then 10 + 0.1g (except for group 4 of FL7659 in which the sample weight was 5 + 0.1g) was weighed out, placed in a 250 mL flask, and extracted with 100 mL of hexane: acetone: ethanol (50:25:25) on a Lab-Line Junior Orbit Shaker (Lab-Line Instruments, Inc., Melrose Park, Ill., U.S.A.) at 140 rpm for 10 min. Water (15 mL) was added to further separate the orange hexane layer from the bottom layer and shaken again for 5 min. After the upper lycopene layer (approximately 50 mL) was pipetted off into a 100 mL beaker, the process was repeated with another 100 mL of the above solvent and then 15 mL of water. The upper layer was pipetted off again and pooled with the first extractant (Sadler and others 1990). The total extraction volume was approximately 100 mL. This mixture was stirred, approximately 4 mL was removed with a 5 mL syringe attached with a 0.2 μm filter to obtain an adequate amount of filtrate which was placed in a 3.7 mL amber vial. From these vials, 0.2 or 0.3 mL was withdrawn and diluted with hexane (HPLC grade) in a 1 mL amber injection vial for HPLC analysis. Each sample was injected into the HPLC instrument in duplicate.

HPLC System

The HPLC system consisted of a series of 4 liquid chromatograph microprocessor-controlled solvent delivery systems, an ISS-100 Intelligent Sampling System (Perkin-Elmer, Norwalk, Conn., U.S.A.) fitted with a 200 μL loop, a Waters 484 Tunable Absorbance Detector (Milford, Mass., U.S.A.), and a Spectra-Physics 4290 integrator (San Hose, Calif.). The column was an Ultrasphere (ODS) (250 × 4.6 mm I.D. particle size of 5 μm) (Supelco Inc., Bellefonte, Pa., U.S.A.) with a SSI high pressure column prefilter, 0.5 m. The wavelength of the detector was set at 460 nm and the sensitivity was set at 0.001. The mobile phase was acetonitrile:methanol:methylene chloride (43.3:43.3:13.4) at a flow rate of 1.5 mL/min. The injection volume was 20 μL. Lycopene eluted at approximately 11 min.

A standard curve of lycopene (90% to 95% pure from Sigma Chemical, St. Louis, Mo., U.S.A.) was run with each set of samples on the HPLC with the following amounts of lycopene: 7.56, 18.9, 37.8, 75.6, and 94.5 ng. These amounts were calculated by reading a 1 mL sample from a lycopene stock solution on a spectrophotometer at a wavelength of 472 nm. Lycopene concentration for each standard was calculated using hexane as background and the equation: $A = \xi cl$ (Hart and Scott 1995), where A is absorbance, ξ is molar extinction coefficient, c is concentration, and l is the thickness of the cuvette. After the stock solution concentration was determined, the various amounts of lycopene needed for the standard curve were calculated and injected on the HPLC.

Effect of Maturity Stage and Cultivar Variation on Tomato Lycopene Content

Four varieties were harvested on December 8, 1997, 'Agriset', 'Solar Set', 'Suncoast' (*og*), and FL7692D (*og*). The tomatoes were harvested at 3 different ripening stages: red ripe (more than 90% of the surface shows red color), breaker (no more than 10% of the surface shows red or pink), and mature green (surface is completely green). The grouping of each variety was the same as previously described.

Approximately twenty tomatoes from each stage and variety were homogenized and stored according to the method specified previously. Some tomatoes at breaker stage were stored in open containers at room temperature (22 to 23 °C) for 0, 6, 9, and 12 d of storage (day 0 being the day after harvest) and then homogenized and analyzed for pH, titratable acidity, and soluble solids content. The remainder of the homogenate was flashed with nitrogen gas and stored at −20 °C in 250 mL plastic amber bottles until they were extracted for HPLC analysis.

The same process was followed for the mature green tomatoes. On day zero (the day after harvest), some were homogenized and analyzed for pH, titratable acidity, soluble solids content, and lycopene as previously described. The remaining day zero mature green tomatoes were treated with ethylene gas at the Horticultural Science Department at the University of Florida. The tomatoes were gassed in a 20 °C chamber for 4 d until they achieved breaker stage. The gas was a 100 ppm ethylene and air mixture. After the fourth day of ethylene treatment, most of the tomatoes were at the breaker stage. They were then stored at room temperature (22 to 23 °C) as previously described for breaker, homogenized, and analyzed on day 6 (day 2 after ethylene treatment), 9 (day 5), and 12 (day 8) after harvest. The homogenates were stored in 250 mL amber plastic bottles at −20 °C until HPLC analysis for lycopene content.

Before HPLC analysis, all extracts from day 0 mature green tomatoes were concentrated 100-fold. This was accomplished by drying the 100 mL extract sample under a Buchi Rotavapor 110 (Brinkmann Instruments Inc., Westbury, N.Y., U.S.A.) which was protected from light by covering with aluminum foil. The dried sample was rinsed with 3 mL of hexane, dried under a stream of nitrogen gas, brought to a 1 mL volume with hexane, and then filtered through a 0.2 μm filter for injection into the HPLC.

Effect of Cooking on Lycopene Content of Tomato

Four red varieties were harvested (June 1, 1998) at the red ripe maturity stage: 'Agriset', FL7765 (*og*), FL7655, and 'Solar Set'. These samples were tested uncooked and then cooked. Uncooked samples were analyzed in the same manner as previously described (5 tomato slices in each group and four groups for each variety). Samples (50 g) used for cooking were taken from the homogenized uncooked samples. Samples were heated in boiling distilled water in 8-oz Fisherbrand Sterile Sampling Bags (Pittsburgh, Pa., U.S.A.) which were flattened by wire mesh to ensure continuity in sample distribution. The sampling bags were 1st tested for heat transfer by using a homogenized tomato sample with a thermocouple to determine 100 °C come up time and cool down time. One thermocouple was placed in the boiling water bath and the other one was placed in the tomato sample. The time for the sample to reach 100 °C was 80 s. Thus, 80 sec were added to the original cooking times of 4, 8, and 16 min. After heating in boiling water for 5.3, 9.3, and 17.3 min, the samples were immediately placed in an ice slurry for rapid cooling. The samples were then frozen at −20 °C until analyzed by HPLC.

The percentage of water loss during the heat treatment was also analyzed. Cooked and uncooked samples of tomato homogenate (10 ± 0.1 g) in aluminum pans were dried in an oven at 93 °C for 6 h and moisture losses determined (Nielsen 1994).

Statistical analysis

An analysis of variance (ANOVA) was performed by statistical analysis system (SAS) using general linear models procedures (SAS Institute Inc. 1989). Duncan's multiple range test was used to obtain comparisons among sample means. Evaluations were based on a $p = 0.05$ significance level.

References

Chew BP. 1995. Antioxidant vitamins affect food animal immunity and health. J. Nutrit. 125:1804-1808.

Conn PF, SchalchW, Truscott TG. 1991. The singlet oxygen and carotenoid interaction. J. Photochem. Photobiol. Biol. 11:41-47.

Devasagayam TPA., Werner T, Ippendorf H, Martin H, Sies H. 1992. Synthetic carotenoids, novel polyene polyketones and new capsorubin isomers as efficient quenchers of singlet molecular oxygen. Photochem. Photobiol. 55:511-514.

Fraser PD, Truesdale MR, Bird CR, Schuch W, Bramley PM. 1994. Carotenoid biosynthesis during tomato fruit development. Plant Physiol. 105:405-413.

Hakala SH, Heinonen IM. 1994. Chromatographic purification of natural lycopene. J. Agric. Food Chem. 42:1314-1316.

Hart DJ, Scott J. 1995. Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. Food Chem. 54:101-111.

Mencarelli F, Saltveit ME. 1988. Ripening of mature-green tomato fruit slices. J. Amer. Soc. Hort. Sci. 113:742-745.

Nielson SS., editor. 1994. Introduction to the Chemical Analysis of Foods. Boston, MA Jones and Bartlett Pub. p 100-101.

Sadler G, Davis J, Dezman D. 1990. Rapid extraction of lycopene and β-carotene from reconstituted tomato paste and pink grapefruit homogenates. J. Food Sci. 55:1460-1461.

SAS Institute Inc. 1989. SAS User's Guide: Statistics. SAS system Version 6. 4th edition. Cary, N.C.: SAS Institute Inc. 1686 p.

Stahl W, Sies H. 1992. Uptake of lycopene and its geometrical isomers is greater from heat-processed than from unprocessed tomato juice in humans. J. Nutrit. 122: 2161-2166.

Thompson AE, Tomes ML, Wann EV, McCollum AK, Stoner AK. 1964. Characterization of crimson tomato fruit color. Amer. Soc. Hort. Sci. 86:610-616.

MS 19990936 received 9/22/99; revised 1/26/00; accepted 4/10/00.

We thank the Florida Tomato Committee for its funding of this research. The assistance of Drs. Jeongmok Kim and Wen-Xian Du in this study is gratefully acknowledged.

Florida Agricultural Experiment Station Journal Series No. R-07115.

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