ASSESSING LYCOPENE CONTENT IN CALIFORNIA PROCESSING TOMATOES

ELISABETH GARCIA and DIANE M. BARRETT[1]

Department of Food Science and Technology
University of California
One Shields Avenue
Davis, CA 95616-8598

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ABSTRACT

Tomatoes constitute the main source of lycopene in the U.S. diet. Growing interest in the potential health-protective role of lycopene is bringing attention to the content of lycopene in tomatoes. A wide range of lycopene content (55–181 mg/kg) was observed in juice prepared from selected cultivars of tomatoes grown in nine California counties. A comparison of cultivars H 8892, H 9665 and Halley 3155 grown in Colusa, Fresno, San Joaquin and Yolo counties during three seasons concludes that mean lycopene concentrations were significantly greater ($P < 0.01$) in 2000 (106 mg/kg) than in 1999 (101 mg/kg) and 2001 (88 mg/kg). An evaluation of nine processing tomato cultivars harvested in one season on four separate dates indicated that lycopene concentration of tomatoes decreases with maturation on the plant. Lycopene concentration of tomatoes is dependent on the growing season, location, cultivar and maturity.

INTRODUCTION

In the evaluation of tomato products such as sauce, purée or paste, color is recognized as a primary factor of quality (Denny 1997). For the processing tomato industry, a fresh tomato color is essential in obtaining tomato products exhibiting superior red color and appearance. The color of raw tomatoes is an index of maturity; during maturation of red cultivars there is a between 10- to 14-fold increase in the concentration of carotenoids, mainly lycopene (Fraser *et al.* 1994). In mature processing tomatoes, lycopene constitutes 80–90% of the total pigments present (Shi and Le Maguer 2000). Although

[1] Corresponding author. TEL: (530) 752-4800; FAX: (530) 752-4759; EMAIL: dmbarrett@ucdavis.edu

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lycopene provides no provitamin A activity, lycopene attracts considerable attention because of its other potential health benefits (Stahl and Sies 1996; Gerster 1997; Giovannucci 1999; Rao and Agarwal 2000) by protecting against oxidative damage implicated in the pathogenesis of several human chronic diseases. The mechanism by which lycopene may exert a protective effect may involve its antioxidant potential. In addition, the protective role of lycopene may be related to its nonantioxidant properties such as the reduction of cellular proliferation and modulation of intercellular gap-junction communication (Stahl *et al.* 2002; Aust *et al.* 2003).

Lycopene is present in foods common to our diet, in particular the tomato, watermelon, pink grapefruit, red guava and red-fleshed papaya (Ong and Tee 1992; Rodriguez-Amaya 1999). At least 85% of our lycopene intake comes from the consumption of tomatoes and tomato products (Bramley 2000). In 2000, the *per capita* consumption of tomatoes in the United States was about 39.5 kg, 80% of which was consumed as canned tomato products (USDA/ERS 2002). The lycopene content of tomatoes depends on the cultivar and maturity stage, and is affected by growing conditions, temperature and humidity, among other factors (Sharma and Le Maguer 1996; Giovanelli *et al.* 1999; Abushita *et al.* 2000; Dumas *et al.* 2003). Tomato breeders are developing high-pigment hybrid processing tomatoes that yield improved red color for tomatoes and tomato products, as well as possess larger concentrations of lycopene.

California produces approximately 94% of the processing tomatoes grown in the U.S.A., corresponding to about 40% of world production. The potential impact of growing location and conditions on the lycopene concentration of tomatoes may bring useful information to breeders and producers of processing tomatoes interested in lycopene accumulation in tomatoes. The objective of this study was to assess the variability in lycopene concentration in processing tomatoes as affected by maturity, cultivar, growing location and season.

MATERIALS AND METHODS

Breeding Cultivars and Planting

In each county, tomatoes were cultivated by cooperating commercial growers as part of a long-term program of evaluation of new tomato cultivars under the coordination of the Department of Food Science and Technology and the Cooperative Extension Program at the University of California, Davis (Murray *et al.* 1999). For each tomato cultivar in each county, plots were 30 m (100 ft) long. There were nine California counties (Fig. 1) involved in the study. All tomatoes were manually harvested at the commercial red mature

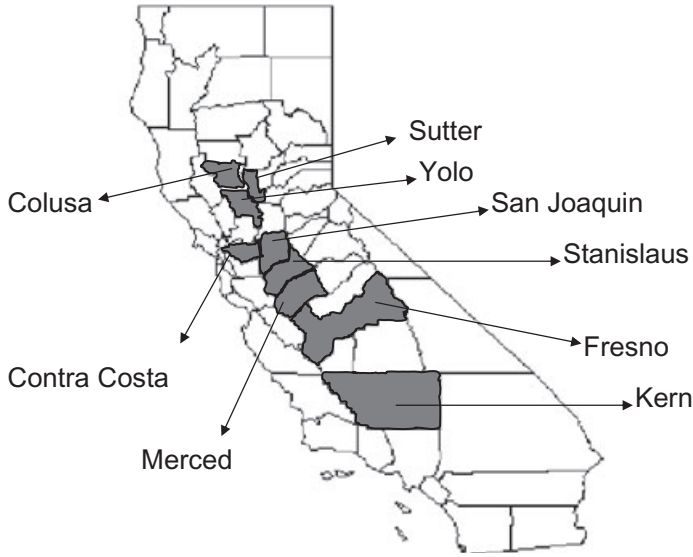

FIG. 1. CALIFORNIA COUNTIES WHERE THE PROCESSING TOMATOES ANALYZED IN THIS STUDY WERE GROWN

stage by a crew from the Department of Food Science and Technology, University of California at Davis. Tomatoes were selected from the middle of the plant, avoiding the crown set (bottom) and top tomatoes. Plants were chosen randomly from the 30 m rows.

Two separate studies were conducted: (1) An assessment of the range of lycopene concentration in tomatoes grown in selected California counties and growing seasons. The number of cultivars analyzed per county in each season and year are presented in Table 1. Tomato cultivars were harvested during the early season (mid-July through mid-August) in three to five California counties, primarily in Colusa, Fresno and Yolo. Most of the tomatoes were harvested during mid-season (mid-August through early October). Counties participating in mid-season trials included Colusa, Fresno, Kern, Merced, San Joaquin, Stanislaus, Sutter and Yolo. Six tomato cultivars were evaluated: CXD 199 (Campbell's Seeds, Davis, CA), H 8892, H 9665, H 9280 (Heinz Tomato Products, Stockton, CA), HyPeel 45 (Seminis Inc., Oxnard, CA) and Halley 3155 (Orsetti Seed Co, Hollister, CA). Cultivars H 9280 and HyPeel 45 were harvested in the early season, and cultivars CXD 199, H 8892, H 9665 and Halley 3155 were harvested in the midseason. Tomato cultivars were grown in replicated plots in the locations indicated in Table 2.

(2) Field holding trials were conducted in the 2001 season in Fresno County and included nine cultivars: Peto 303 (Petoseed, Saticoy, CA), H 8892,

TABLE 1.
LYCOPENE CONCENTRATION OF TOMATOES

Season/County	Year	Number of cultivars	Lycopene content (mg/kg fresh weight)		No. days*	
			Range	Mean	>32.2C (>90F)	>37.7C (>100F)
Early season						
Colusa	1999	27	72.3–103.9	84.4 ± 7.8	28	6
	2000	21	71.9–138.1	99.5 ± 13.4	37	5
	2001	21	72.0–110.9	90.1 ± 10.9	41	11
Fresno	2000	21	55.0–128.1	98.4 ± 14.4	43	12
	2001	21	68.9–120.7	94.3 ± 13.3	57	25
Contra Costa	2000	21	91.6–144.8	116.3 ± 13.0	35	2
	2001		59.0–127.5	78.8 ± 17.3	41	4
Stanislaus	1999	27	92.3–132.9	111.6 ± 11.0	37	10
Yolo	1999	27	93.4–132.6	107.1 ± 10.6	37	6
	2000	21	65.0–116.3	99.0 ± 10.6	40	4
	2001	21	76.9–119.6	93.3 ± 11.1	47	14
Mid season	1999	46	87.6–130.4	108.9 ± 10.0	66	10
Colusa	2000	42	69.3–114.7	89.8 ± 10.3	58	11
	2001	38	71.7–114.7	89.5 ± 9.2	79	18
Fresno	1999	46	87.7–123.9	103.9 ± 9.8	58	13
	2000	42	81.4–137.1	110.3 ± 12.5	55	16
	2001	40	60.7–138.6	85.0 ± 13.6	62	25
Kern	2000	37	79.0–163.4	113.1 ± 17.9	60	7
	2001	38	100.0–160.7	120.7 ± 15.0	58	10
Merced	1999	45	81.9–122.3	102.9 ± 10.8	56	13
	2000	42	93.9–181.4	127.9 ± 15.7	69	25
San Joaquin	1999	46	79.9–123.5	105.5 ± 8.6	52	6
	2000	42	100.5–159.0	130.2 ± 12.9	67	5
	2001	38	68.4–116.4	86.8 ± 10.1	70	11
Stanislaus	2000	42	93.6–131.9	110.9 ± 9.6	32	0
	2001	38	68.4–108.6	84.9 ± 9.3	58	2
Sutter	1999	45	90.7–132.5	106.1 ± 10.4	55	9
	2000	42	99.5–168.4	131.2 ± 13.9	65	8
	2001	38	82.1–118.0	98.2 ± 8.2	78	17
Yolo	1999	60	82.6–132.7	100.6 ± 11.2	54	10
	2000	42	81.2–153.4	112.8 ± 13.0	53	7
	2001	38	78.4–115.7	96.0 ± 7.8	75	17
Late season Fresno	1999	54	80.6–126.4	108.4 ± 9.8	93	11

* Number of days from planting to harvesting.

H 9492, H 9553, H 9665, H 9775, H 9995, H 9998 and Halley 3155. The tomato cultivars were planted on April 5, 2001 and harvested on four separate dates, 8/15, 8/21, 8/30 and 9/5. Four field replicates were analyzed per tomato cultivar per harvest date. Air temperature and degree-days were retrieved from

TABLE 2.
LYCOPENE CONCENTRATION OF SELECTED TOMATO CULTIVARS

Cultivar	Location (County)	Lycopene (mg/kg fresh weight)		
		1999	2000	2001
H 9280	Colusa	76.1	94.9	89.4
	Fresno		96.8	90.5
	C. Costa			61.2
	S.Joaquin		109.3	
	Stanislaus	101.1		
	Yolo	99.9	92.2	89.6
HyPeel 45	Colusa	78.6	84.9	78.7
	Fresno		96.8	87.5
	C. Costa			68.1
	S.Joaquin		109.3	
	Stanislaus	97.5		
	Yolo	95.2	92.8	80.2
CXD 199	Colusa	113.6	103.8	92.7
	Fresno	112.5	126.8	91.1
	Kern		134.6	146.8
	Merced	102.5	145.1	
	Stanislaus		109.9	88.4
	San Joaquin	110.0	126.2	99.2
	Sutter	111.0		101.9
	Yolo		130.7	101.0
H 8892	Colusa	111.5	82.2	89.7
	Fresno	110.4	100.3	84.9
	Kern		114.8	109.7
	Merced	108.6	129.4	
	Stanislaus		116.1	79.2
	San Joaquin	106.6	127.3	94.3
	Sutter	99.4		99.9
	Yolo	97.4	108.7	98.7
H 9665	Colusa	105.1	85.3	88.0
	Fresno	101.3	106.4	80.8
	Kern		100.3	113.0
	Merced	106.6	119.0	
	Stanislaus		102.9	82.9
	San Joaquin	98.4	120.4	89.5
	Sutter	91.5		92.7
	Yolo	95.6	110.6	90.5
Halley 3155	Colusa	101.4	92.0	84.7
	Fresno	99.8	109.1	81.2
	Kern		87.3	117.6
	Merced	102.8	131.0	
	Stanislaus		103.4	95.6
	San Joaquin	98.8	119.8	82.7
	Sutter	90.4		101.3
	Yolo	88.1	120.4	91.0

Early Season cultivars: H 9280 and HyPeel 45. Mid Season cultivars: CXD 199, H 8892, H 9665 and Halley 3155.
Blank cells indicate instances where cultivars were not commercially grown in the year and/or location.

the UC-IPM Statewide Integrated Pest Management Project website (UC-IPM 2001).

Sample Preparation

For each tomato cultivar, 13.5 kg of tomatoes was washed, towel dried and sorted for defects. Tomatoes were cut longitudinally into two halves, with half used for raw color analysis and the other placed in a microwaveable glass dish until a total weight of approx. 1.3 kg was reached. The weighed dish was covered and heated to simulate a hot break process in a microwave oven, 6 min at 1400 W, followed by 6 min at 700 W. The temperature reached in this process was 95C, the temperature at which was previously found to inactivate enzymes. Immediately after heating, the dish was cooled in ice water, and the cooled tomatoes reweighed. Water was then added to compensate for losses caused by evaporation during heating. The tomatoes were pulped with a lab pulper (Food Processing Equipment Co., Sacramento, CA) and adapted with a 0.84 mm (0.033 in) screen to separate seeds and skin. The single-strength juice was frozen at −32C until analysis.

The microwave hot break procedure was developed in the Department of Food Science and Technology (Leonard *et al.* 1980) so that the time-consuming process of concenting the tomato juice to paste would not be required in the evaluation of tomato cultivars. The tomato cultivars were both concentrated to paste following a typical hot break process and given a microwave hot break for more than five growing seasons in the 1970s. Statistical correlations of the soluble solids and Bostwick consistency values of concentrated paste and microwaved juice allowed for the juice parameters to serve as a predictive tool for paste quality and yield (Leonard *et al.* 1980).

Lycopene Analysis

All microwaved tomato juices were analyzed for lycopene content by a spectrophotometric method adapted by Anthon and Barrett (2001). Lipid soluble components were extracted with a solution of ethanol and hexane (4:3 v/v), the phases were separated and the absorption of the hexane phase was read at 503 nm. Hexane phase extractions were analyzed in duplicate and results calculated using the value of 172/nM as the extinction coefficient for lycopene in hexane. Results were expressed in milligrams of lycopene per kilogram of fresh tomato juice.

Color Determinations

Approximately 300 g of microwaved tomato juice was used for color evaluation. The juice was stirred prior to analysis for a homogeneous solution.

Colorimeter determinations were taken in time intervals no longer than five minutes to prevent tomato juice separation. The color of natural single-strength tomato juice was determined using a Hunter tri-stimulus colorimeter (Model LabScan 5100, A head, Reston, VA), previously standardized using a red tile ($L = 25.24$, $a = 25.85$, $b = 11.7$). Colorimeter determinations were recorded as *L*- *a*- and *b*-values. Hue angle (Francis 1995) was calculated from the chromaticity values.

Statistical Analysis

A cultivar evaluation trial comprising three tomato cultivars (H 8892, H 9665 and Halley 3155) grown in four counties (Colusa, Fresno, San Joaquin and Yolo) in the three consecutive years of the study were submitted to analysis of variance (ANOVA) using the SAS system (SAS 2002). Results obtained from the field holding trial were analyzed using ANOVA models, comparisons were calculated using least squares means and the Tukey-Kramer adjustment for multiple comparisons (SAS 2002) was utilized. Significance was predetermined at $P \leq 0.01$.

RESULTS AND DISCUSSION

Analyses were performed on microwaved tomato juice. The mean lycopene content of 12 tomatoes was 133 mg/kg for the raw juice, and 135 mg/kg for the microwaved juice. A paired Student *t*-test revealed no significant statistical difference in lycopene content between the raw and microwaved tomato juices.

Lycopene in California Processing Tomatoes

Nine California counties were included in this study because they encompass a wide range of growing conditions. Among these growing areas there are variations in air temperature, rainfall, soil and water, which may affect each tomato cultivar differently (Murray *et al.* 1999). Tomatoes destined for commercial processing are currently grown in all nine counties and it is of interest to breeders, growers and processors to evaluate yield, disease resistance and quality differences.

The ranges of lycopene content in tomatoes grown during selected seasons and years in the nine counties are presented in Table 1. These results are the mean of the tomato cultivars planted in each county, which range from 21 to 46 cultivars per county. The smallest lycopene concentration detected in single-strength juice was 55.0 mg/kg fresh weight, obtained with tomatoes

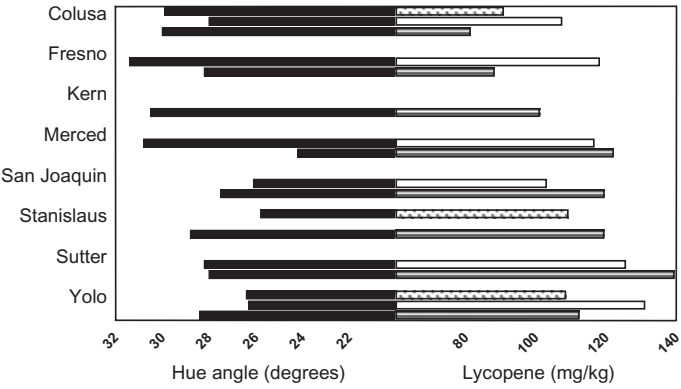

FIG. 2. COLOR VALUES (LEFT) AND LYCOPENE CONTENT (RIGHT) OF PROCESSING TOMATO CULTIVAR BRIGADE GROWN IN DIFFERENT CALIFORNIA COUNTIES AND SEASONS.
Hatched bars represent 1999 early season; open bars for 1999 midseason; and longitudinally striped bars for 2000 midseason.

harvested during the early season of 2000 in Fresno County. The largest lycopene concentration obtained was 181.4 mg/kg in the juice of mid-season tomatoes grown in 2000 in Merced County, reflecting a 3.3-fold variation in lycopene concentration. A wide range of lycopene content in tomato juice is also reported in the literature: 78.3 mg/kg in commercial U.S. tomato juice (Nguyen and Schwartz 1998), 82.0–110.0 mg/kg in tomato juice sold in Hungary (Lugasi *et al.* 2003), 61.6 mg/kg in commercial Brazilian tomato juice (Tavares and Rodriguez-Amaya 1994) and 122.0 mg/kg in juice prepared from hydroponically grown Laura cultivar tomatoes (Arias *et al.* 2000). Mean lycopene values during this study period ranged from 78.8 to 131.2 mg/kg juice. In general, early-season tomatoes contained less lycopene than midseason tomatoes. Up to 4-fold variations in lycopene concentrations are reported (Dumas *et al.* 2003) in tomatoes from Southern Italy, and up to 3-fold variations in tomatoes grown in Hungary (Abushita *et al.* 1997).

Color (expressed as Hue angle) and lycopene concentration from tomatoes planted in selected locations and grown in selected seasons or years are illustrated for Brigade cultivar (Fig. 2). The effect of season and year may be observed by comparing results from Colusa and Yolo Counties, where the Brigade cultivar was harvested both in the early and midseasons of 1999 and in the midseason of 2000. Tomato pigment concentrations are greater in tomatoes grown outdoors during the summer, particularly during the midseason (Brimelow 1987). In the year 2000, lycopene concentrations of the Brigade cultivar were smaller than lycopene concentrations in midseason of

the previous year in Colusa, Fresno and Yolo Counties, while in 2000, lycopene concentrations were larger in tomatoes from Merced, San Joaquin and Sutter Counties.

Lycopene accumulation in tomatoes is affected by cultivar and maturity, as well as the environment. Although light is very important during growth and development and increases carotenoid concentration in tomato seedlings (Giuliano *et al.* 1993; Britton 1998), tomatoes mature and become red even in the darkness and detached from the plant. As early as 1913, Khudairi (1972) reported that temperatures greater than 30C (86F) impaired lycopene synthesis. Cultivar VF-145-21-4 produced tomatoes that were less red when grown at 35C day temperatures when grown in soil with adequate nitrogen levels or under nitrogen stress. Tomatoes of more attractive color were produced at day temperatures ≤30C (Luh *et al.* 1973). Even though temperatures greater than 30C lead to the inhibition of lycopene synthesis in normal red cultivars of tomatoes, when the temperature is less than 30C, lycopene synthesis is restored. Such effects of temperature are dependent on the cultivar (Britton 1998).

The number of days reaching maximum air temperatures greater than 32.2C (90F) and 37.8C (100F) in selected growing locations in this study were quite variable during the three years investigated (Table 1). This temperature variability may contribute to the smaller concentrations of lycopene observed in tomatoes from counties subjected to particularly high temperatures in 2001. On the other hand, the large lycopene concentrations observed in 2000 may be related to more suitable climatic conditions for lycopene accumulation. Although several genes control tomato pigmentation, the environment can mask genetic differences. In a study on genetic and environmental effects on tomato color, Sacks and Francis (2001) concluded that most of the color variation observed in their study could be related to the variation between and among tomatoes planted in selected plots. Within-plot tomato color was related to microenvironment and tomato maturity. Such sources of variation are believed to obscure genetic differences among tomatoes.

Tomato Cultivars versus Growing Locations

Table 2 presents means of lycopene concentration for the six cultivars grown in the seasons from 1999–2001. Because the tomatoes analyzed in this study were obtained from commercial growers, there were instances where cultivars were not available in some growing locations or seasons. The smallest lycopene concentration (59 mg/kg) was found in juice from cv. H 9280 tomatoes grown in Contra Costa county in 2001. The greatest lycopene concentration (153 mg/kg) was found in juice from cv. CXD 199 tomatoes

grown in Merced County in 2000, a 2.6-fold difference in lycopene concentration.

The most complete comparison of the effect of growing location on lycopene concentration can be drawn from cv. H 8892, H 9665 and Halley 3155 grown in four counties, Colusa, Fresno, San Joaquin and Yolo during the 1999, 2000 and 2001 growing seasons. ANOVA calculations identified year and county as highly significant ($P < 0.001$), and differences among lycopene concentration in selected cultivars ($P = 0.07$) were important. The year by cultivar interaction was significant ($P = 0.01$) and the interaction between year and county was highly significant ($P < 0.0001$).

Mean lycopene concentrations were greatest in 2000 (106 mg/kg), followed by 1999 (101 mg/kg) and 2001 (88 mg/kg). These differences in the lycopene concentration in tomatoes grown in selected years were all statistically significant ($P < 0.01$). The means of lycopene concentration in tomatoes over years and cultivars from San Joaquin (104 mg/kg) and Yolo (101 mg/kg) counties were significantly greater ($P < 0.01$) than the means of lycopene concentration in tomatoes from Colusa County (93 mg/kg). Lycopene concentrations of tomatoes from Fresno County (97 mg/kg) were significantly smaller than those of lycopene concentration of tomatoes from San Joaquin County but not significantly smaller than lycopene concentrations of tomatoes from Yolo County. No statistical differences were observed in lycopene concentrations of tomatoes grown in Fresno or Colusa counties. Statistically significant interactions were observed between years and cultivars ($P < 0.01$) and between years and counties ($P < 0.001$) but not between cultivars and counties ($P = 0.49$).

These analyses suggest the following observations. First, higher temperatures result in smaller lycopene concentrations in tomatoes. For example, in 2000, the year with the greatest mean lycopene concentration in tomatoes, there were five and seven days with maximum temperatures greater than 37.7C in San Joaquin and Yolo counties, respectively. In contrast, there were 11 and 16 days with maximum temperatures greater than 37.7C in Colusa and Fresno counties, respectively, supporting our conclusion that high temperatures tend to reduce lycopene concentration in tomatoes. Second, the interactions between years and both cultivars and counties have implications for plant-breeding programs with goals of increasing the lycopene concentration in tomato cultivars. Interactions between years and cultivars suggest that multi-year testing is invaluable for identification of genotypes with greater, more stable lycopene concentration in tomatoes. Although no significant interactions were observed between counties and cultivars, the significant interactions between years and counties suggest that multilocation trials are valuable as well for determining the breadth of adaptation of potential new tomato cultivars.

TABLE 3.
LYCOPENE CONCENTRATION OF TOMATO CULTIVARS IN FIELD HOLDING TRIALS

Cultivar	Lycopene concentration (mg/kg fresh weight)				
	1st harvest	2nd harvest	3rd harvest	4th harvest	Mean
Halley 3155	94.3	89.2	90.1	75.8	**87.4**
H8892	96.0	93.7	101.3	78.6	**92.4**
H9492	97.7	97.0	90.7	77.0	**90.6**
H9553	96.8	87.7	92.4	69.4	**86.6**
H9665	84.0	88.6	91.0	78.0	**85.4**
H9775	83.9	84.9	86.2	82.0	**84.3**
H9995	96.7	90.7	81.4	79.4	**87.1**
H9998	94.1	92.8	92.4	78.9	**89.6**
Peto 303	95.5	94.4	91.3	86.9	**92.0**
Mean	**93.2**	**91.0**	**90.8**	**78.4**	

Values are mean of four field replicates.

Lycopene Stability During Maturation on the Plant

Wild tomatoes are native to South America from a region where tomato plants grow under moderate temperatures (Cooper 1972) with a mean daytime maximum of 19C (66F). However, contemporary processing tomato cultivars are hybrids bred to withstand California Central Valley climatic conditions. In the processing tomato industry it is a common practice to grow tomatoes under such conditions and even to cut water supply before harvesting. Cutting the water supply before harvest helps achieve larger soluble solid concentrations in tomatoes, but may not be appropriate when cultivation targets increased lycopene accumulation because lycopene synthesis is impaired.

Mean lycopene concentration from four harvests of the 2001 midseason in Fresno County are presented in Table 3. Calculations indicate that the interaction between harvest date and cultivar was not significant. However, the lycopene concentration in tomatoes from the fourth harvest is smaller ($P < 0.0001$) than the previous three harvests. Also, color determinations of the fourth harvest were statistically less red than the first three harvests. Prolonged exposure to high temperatures is detrimental both to lycopene accumulation and tomato color. A negative effect of high temperature on lycopene concentration was reported for the bittermelon fruit (*Momordica charantia* L), which accumulates various carotenoids in selected tissues. Lycopene was not detected in the pericarp of mature bittermelon, but accumulated in substantial amounts in the seed aril of bittermelon matured at 25C (Tran and Raymundo 1999). However, during ripening at 35C, total carotenoid and lycopene

concentration of the seed aril were 83% and 94% smaller, respectively, when compared to bittermelon ripened at 25C.

The avoidance of lengthy field-holding delays will minimize potential pigment losses related to high temperatures in the field. When targeting maximum concentrations of lycopene, it is advisable to reconsider the common practice of holding mature tomatoes in the field while waiting for processing, particularly in regions where tomatoes are submitted to long periods of high temperature. Moreover, the possible association between agronomic practices (Dumas *et al.* 2003), environment and lycopene accumulation for each new cultivar should be evaluated in multilocation, multiyear evaluation trials. The potential association between lycopene accumulation and tomato cultivar, growing conditions and year/season must be considered when evaluating new cultivars. For an appropriate assessment of the variation in cultivar lycopene concentration and color, multilocational, multiyear evaluation trials are necessary. Variations in lycopene concentrations in tomatoes described in this study should be taken in future health claims on minimum quantities of dietary intake for tomato products are recommended as a source of specific minimum intakes of lycopene.

CONCLUSIONS

Temperatures greater than 32.2C (90F) during the growing season result in smaller lycopene concentrations in tomatoes. Growing season or year and growing location are highly significant factors affecting the lycopene concentration in tomatoes. Therefore, multiyear and multilocational testing of tomatoes is invaluable for identification of genotypes with greater, more stable lycopene concentration. Lycopene concentrations decline in tomatoes during maturation in the field; therefore, extended field holding is undesirable.

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