# Processing Tangerine Tomatoes: Effects on Lycopene-Isomer Concentrations and Profile

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**ABSTRACT: Because lycopene is a powerful biological antioxidant, its delivery to humans is of major concern. *cis*-Lycopene isomers are more bioavailable than the all-*trans* isomers and thus more efficiently absorbed. Tangerine tomatoes, whose lycopene isomeric content is almost all *tetra-cis*, provide a useful food source for comparing *cis*- and *trans*-isomer absorption. Tangerine tomatoes were processed into sauce in the Univ. of California, Davis Pilot Plant for subsequent use in a human feeding study described in another publication. Samples were taken at several stages during processing and carotenoids extracted and analyzed for carotenoid-isomer profiles and concentrations. Analyses showed that total lycopene concentration decreased considerably during the 1st step of processing, which included heating and juicing operations. Processing resulted in a large decrease in *tetra-cis* lycopene concentration accompanied by increases in *trans*- and other *cis*-lycopene isomers.**

**Keywords: lycopene, lycopene isomers, processing, Tangerine tomato, tomato sauce**



## Introduction

Tomatoes and tomato products have become of great interest because of both epidemiological and experimental evidence on beneficial health effects in humans and animals (Giovannucci and others 1995, 1999; Clinton and others 1996, 1998; Boileau and others 1999; Rao and Agarwal 2000). Lycopene, the compound responsible for the red color of tomato and representing approximately 80% to 90% of its total carotenoid content (Davies and Hobson 1981), is believed to impart beneficial effects in reducing the risk of prostate and other cancers (Giovannucci and others 1995, 1999; Clinton and others 1996, 1998; Boileau and others 1999), cardiovascular disease (Rao and Agarwal 2000), and protection against harmful rays of the sun (Ribayo-Mercado and others 1995; Stahl and others 2001). Because lycopene was found to be the most powerful biological antioxidant (DiMascio and others 2000), the mechanism of this protection is believed to be via quenching of free radicals that cause oxidative damage to cells and tissues.

Much evidence has also accumulated showing that the *cis*-lycopene stereoisomers are more bioavailable (Stahl and Sies 1992; Clinton and others 1996; Gartner and others 1997; Schierle and others 1997; Boileau and others 1999; Erdman 2005; Unlu and others 2007) than the *trans*-isomer, which is the predominant stereoisomer found in raw red tomato. Bioavailability depends first on the absorption of lycopene through the intestinal wall into the plasma. *Cis*-isomers of lycopene are better absorbed than the all-*trans* isomer. Various factors are cited (Boileau and others 1999) to explain this finding: greater solubility in micelles, preferential incorporation into chylomicrons, less tendency to aggregate and crystallize, more efficient volatilization in lipophilic solutions, and easier transport within cells, across plasma membranes, and the tissue matrix than the all-*trans* isomer. However, little evidence is available on the absorption of specific *cis*-lycopene isomers. Cooking and processing increase the bioavailability of lycopene by softening cell walls, thereby making lycopene in tomato tissues more accessible, and by conversion of some of the *trans*-lycopene isomers to *cis*-isomers (Nguyen and Schwartz 1998; Shi and others 2002). Evidence also has been found indicating isomerization of all-*trans* into *cis*-isomers in the gastrointestinal tract (Clinton and others 1996; Boileau and others 1999).

The Tangerine tomato contains primarily the *tetra-cis* isomer of lycopene (7,7', 9,9'-*tetra-cis* lycopene) (Clough and Pattenden 1979; Johjima 1993). These tomatoes are grown commercially in the Central Valley of California and were available in large quantities for processing. We were interested in using Tangerine tomatoes to investigate differences in bioavailability between *cis*- and *trans*-lycopene isomers in human subjects fed meals incorporating tomatoes that contain primarily either *trans*- or *cis*-lycopene isomers (Burri and others 2007).

Since the completion of our studies, the results of a similar study have been published (Unlu and others 2007). Their results are consistent with ours; however, different methods were used. We will discuss these differences along with our results.

## Materials and Methods

### Tangerine tomato processing

Tangerine tomatoes (*Solanum lycopersicum*, cv. Tangerine) were purchased from Eatwell Farm (Davis, Calif., U.S.A.) and delivered to the Univ. of California, Davis Pilot Plant to be processed into tomato sauce. The procedure used to process these tomatoes was developed by Leonard and others (1980) and has been used routinely in evaluating quality of raw and cooked tomatoes and tomato products (Barrett 2001; Garcia and Barrett 2006a, 2006b). A flow diagram of the entire process is presented in Figure 1.

Approximately 227 kg (500 lb) of Tangerine tomatoes were processed in 5 separate batches, weighing 52 to 118 lb, using the following procedure: Each delivery of tomatoes was received on the Friday before the week of processing. Tomato fruit were spread in

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flats in a single layer and stored at 4 to 7 °C (40 to 45 °F) for 2 d until the following Monday (or once on Tuesday following a Labor Day weekend). Processing commenced on the morning after the weekend by removing the fruit from chilled storage and weighing. Tomatoes were washed by hand, rinsed, blotted free of water, and placed into flats. Raw tomato fruit reference samples were refrigerated for analysis later.

A microwave hot break process was developed to simulate a commercial hot break step (Leonard and others 1980) and is used to inactivate enzymes in processes to evaluate tomato cultivar qualities (Barrett 2001; Garcia and Barrett 2006a, 2006b). Washed tomatoes were cut into 0.64- to 1.27-cm (1/4- to 1/2-in) slices. Approximately1300 g tomato fruit were loaded into a microwave-proof bowl and covered with plastic wrap. The bowl was placed in a microwave oven, heated for 6 min at full power (commercial 1400-watt microwave oven), rotated 90° in the microwave oven cavity, and heated for an additional 6 min at one-half power. Heated tomatoes were then transferred to cold storage for several hours before the juicing process.

Tomato juice was prepared from cooked tomatoes using a laboratory finisher unit, a screen through which cooked tomato was passed. The screen had 0.08-cm (0.033-in) perforations, which separated tomato serum and pulp solids from skin, seeds, and other particulate material. Juice was collected in buckets for refrigerated storage, usually overnight, and skins and pulp were discarded.

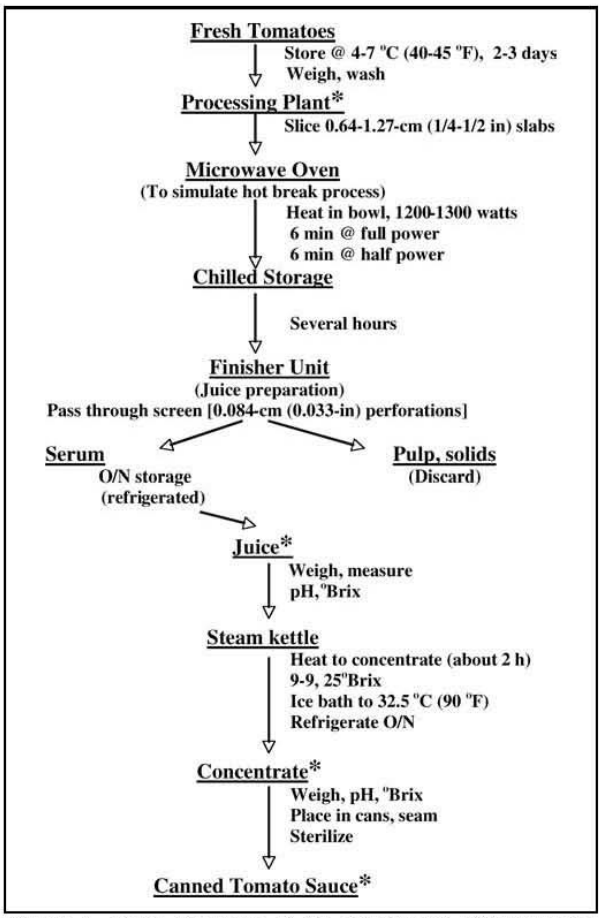


**Figure 1—Flow diagram of the treatment of Tangerine tomatoes after delivery to the pilot plant at the Univ. of California, Davis, for processing. (*Samples taken for lycopene analysis.)**

On the following day, juice was weighed and its pH and °Brix measured. The pH of the juice ranged from 3.93 to 4.4, and the soluble solids was 6.0 to 6.5 °Brix. Juice was added to a steam kettle (19 L or 5 gal) for concentration. Approximately 2 h of heating with hand stirring was required to obtain a °Brix reading of about 9.0 to 9.25, an increase in solids of about 50%. When the desired soluble solids were obtained, the sauce was transferred to a bucket and cooled rapidly in an ice bath. After the sauce temperature dropped to about 32 °C, it was refrigerated and held overnight. The chilled tomato sauce was then weighed, generally on the 3rd and final day of processing, and pH and soluble solids were determined. The soluble solids content found in commercial tomato sauce is 10 °Brix (Marquardt 2002). In the process described here, pH was 4.1 to 4.2, and the soluble solids was 10 °Brix. This product formed the tomato sauce base, which was then canned and sterilized.

Batches of tomato sauce base were then combined in a container and placed into a hot water bath to warm the sauce to 32 to 35 °C. It was then poured into kettles for ease of handling and transferred to 300 × 407 (3-in diameter, 4 7/16 in high) cans. Cans were filled to within 0.64 to 1.3 cm from the top and lids placed on top. They were then seamed with a Rooney can seamer (Rooney Machine Co., Bellingham, Wash., U.S.A.). During this process, a 30- to 40-kPa (18- to 21-in) vacuum was drawn into the can to remove residual air and to reduce stress to containers and seams resulting from high-pressure build-up developed in the autoclave-style, in-can sterilization process. Seamed, sealed cans were transferred to a rotary FMC Steritort system (FMC Corp., Madera, Calif., U.S.A.) for sterilization. The sterilization process is similar to a pressure cooker used in home canning, employing a temperature of 104 °C for 44 min to destroy organisms having public health concern. The thermal process was preceded by a 3-min period to allow the sterilizer to exhaust all air from the vessel and to attain proper temperature in the cooker. Sterilization was followed by a 10-min cooling cycle using ambient-temperature water. Processed cans were then removed from the sterilizer and stacked in front of a fan to air dry the surfaces of the cans.

## Carotenoid analyses

**Materials.** Dichloromethane, 99.9%, HPLC-grade, and anhydrous tetrahydrofuran, 99.9%, were purchased from Aldrich Chemical Co. (Milwaukee, Wis., U.S.A.). Methanol (MeOH), HPLC-grade, methyl-t-butyl ether (MTBE), and ethyl acetate (EtOAc), HPLC-grade, were purchased from Fisher Scientific (Fair Lawn, N.J., U.S.A.). Lycopene for standard solutions was extracted and purified from berries of autumn olive (*Elaeagnus umbellata* Thunberg) plants, which were a gift from Beverly A. Clevidence (Beltsville Human Nutrition Research Center, UDSA, ARS, Beltsville, Md., U.S.A.). Also for standard solutions, β-carotene (type IV from carrots), mixed isomer carotene (from carrots), and lutein (from alfalfa) were purchased from Sigma Chemical Co. (St Louis, Mo., U.S.A.).

**Methods.** Dry weights of tomato samples were determined using a Model AVC-80 microwave moisture/solids analyzer (CEM Corp., Matthews, N.C., U.S.A.). Samples of tissue were placed between 2 tared glass-fiber pads and heated at 50% power for 4.5 min, which was sufficient time for water loss from the tomato sample to be complete. Moisture content (or percent solids) was determined by difference in weight after drying.

Carotenoids were extracted from tomato fruit tissues (whole fruit minus seeds), juice (after the juicing process—skin and seeds

removed), or sauce (juice concentrated by cooking) by the method described by Ishida and others (2001) with modifications to maximize extraction of both polar and nonpolar species. Tomato fruit samples (0.5 to 1.0 g) were weighed and homogenized, using an Omni-Mixer (Sorvall/DuPont Medical Products, Newtown, Conn., U.S.A.), and equal volumes of methanol and dichloromethane were added, followed by another half volume of distilled water. The mixture was gently inverted several times and the phases allowed to separate. The lower (dichloromethane) layer was transferred to a new vial, and the upper aqueous (methanol) layer mixed again with equal amounts of the 2 solvents and the dichloromethane extracts pooled; the upper layer was washed repeatedly until colorless and the plant tissue, which remains at the interface between the 2 layers, white. Combined extracts containing carotenoids were dried under a stream of nitrogen gas in the dark and stored at −20 °C. Carotenoids were analyzed using a reversed-phase high-performance liquid chromatographic (HPLC) system. Just before analysis, dried extracts were resuspended in 2-mL tetrahydrofuran and passed through a 0.2-$\mu$m nylon filter. Samples were held at 10 °C in the autosampler compartment of the HPLC until injection. Aliquots (25 $\mu$mL) were injected into a Waters HPLC equipped with a model 2690 Separations Module, model; 996 Photodiode Array Detector, and a $C_{30}$ carotenoid column (4.6 × 250 mm i.d.; 3-$\mu$m particle diameter, polymeric) (Waters Corp., Milford, Mass., U.S.A.) for analysis. Carotenoids in tomato samples were analyzed essentially according to the HPLC method described in Ishida and Chapman (2004), except that a mobile phase of methyl *t*-butyl ether (MTBE):methanol (MeOH):ethyl acetate (EtOAc) (45:40:15) was used. *Cis*- and *trans*-lycopene isomers were identified by their absorption spectra and retention times (Ishida and others 2001; Ishida and Chapman 2004). No standards were available for the various *cis*-lycopene isomers. Therefore, we were able to identify conclusively only the *tetra-cis* isomer of lycopene, which has a distinctive absorption spectrum, but could not distinguish among other specific *cis*-isomers of lycopene. Because our mobile phase was very similar to that used by Fröhlich and others (2005) and because the same type of column was used, we can assume that the order of elution of the *cis*-lycopene isomers was also similar. Based on the mass spectrometric data of Fröhlich and others (2005), 3 *cis*-lycopene isomer peaks in Figure 2B, beginning at about 8 min, are 5,9'-*cis* lycopene, 9-*cis* lycopene, and 5,9-*cis* lycopene, and the peak following all-*trans* lycopene at about 13.25 min is 5-*cis*-lycopene. Both *trans*- and *cis*-isomers of lycopene were quantified by using the all-*trans* lycopene calibration as done in other studies (Ishida and others 2001; Böhm and others 2002; Ishida and Chapman 2004; Moraru and Lee 2005; Fröhlich and others 2005, 2006). *Cis*-lycopene isomers, other than *tetra-cis* lycopene, were grouped together for quantification.

## Results and Discussion

### Carotenoid profile

The carotenoid profile of the Tangerine tomato was examined after extracting carotenoids from samples of the raw fruit and are

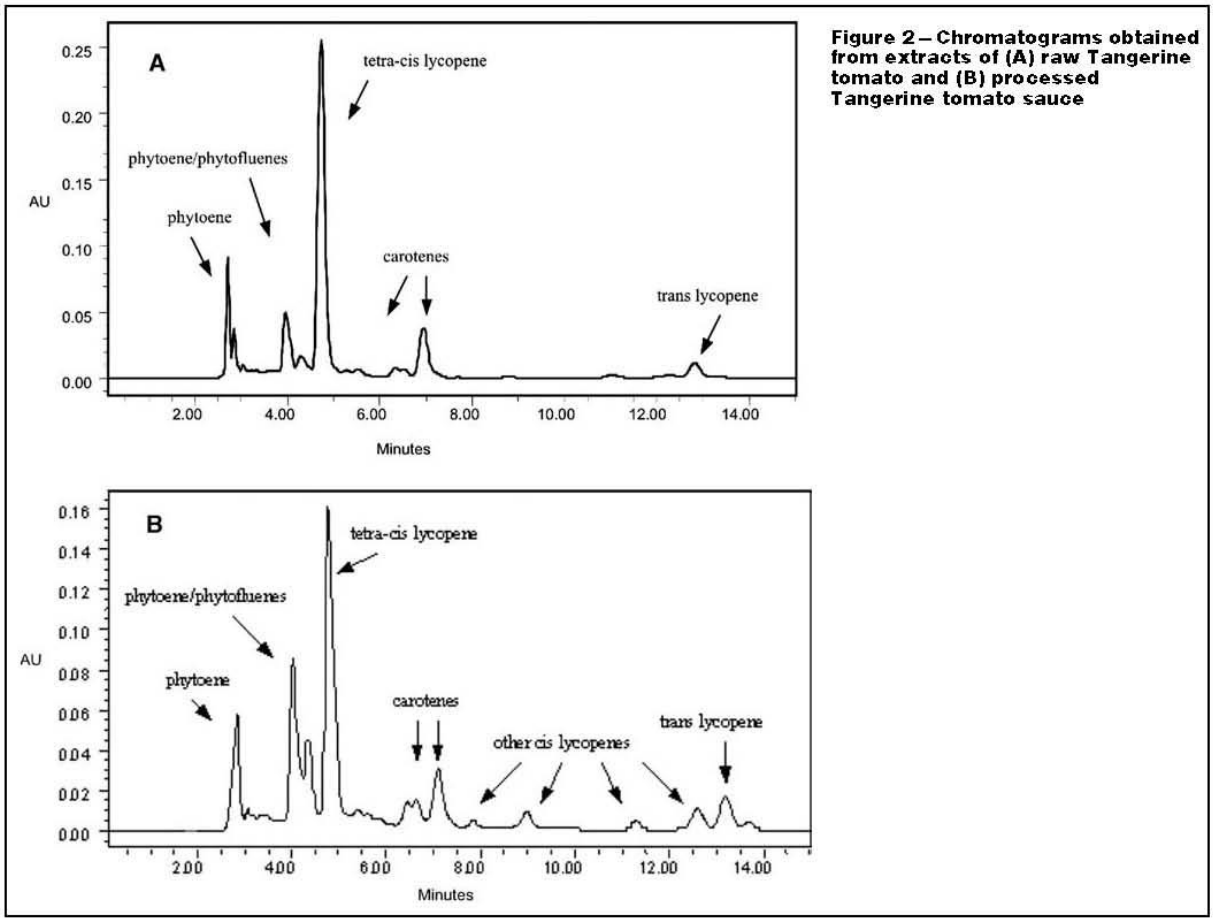


**Figure 2 – Chromatograms obtained from extracts of (A) raw Tangerine tomato and (B) processed Tangerine tomato sauce**

presented in Figure 2A. Our results essentially confirm earlier results that we obtained from different cultivars of Tangerine tomatoes (Hayes and others 1998) and those reported by Clough and Pattenden (1979) and Johjima (1993), that is, that the lycopene-isomer content of Tangerine tomatoes is very high in 7,7',9,9'-*tetra-cis* lycopene (80% to 90%). Lycopene is primarily present as the *tetra-cis* isomer. Small amounts of phytoene, phytofluene, carotenes, and smaller amounts of other *cis* and the all-*trans* isomer of lycopene are also present. In contrast, raw red tomatoes, as well as cooked red tomatoes, contain primarily the *trans*-isomer of lycopene (Stahl and Sies 1992; Clinton and others 1996; Schierle and others 1997; Ishida and others 2001).

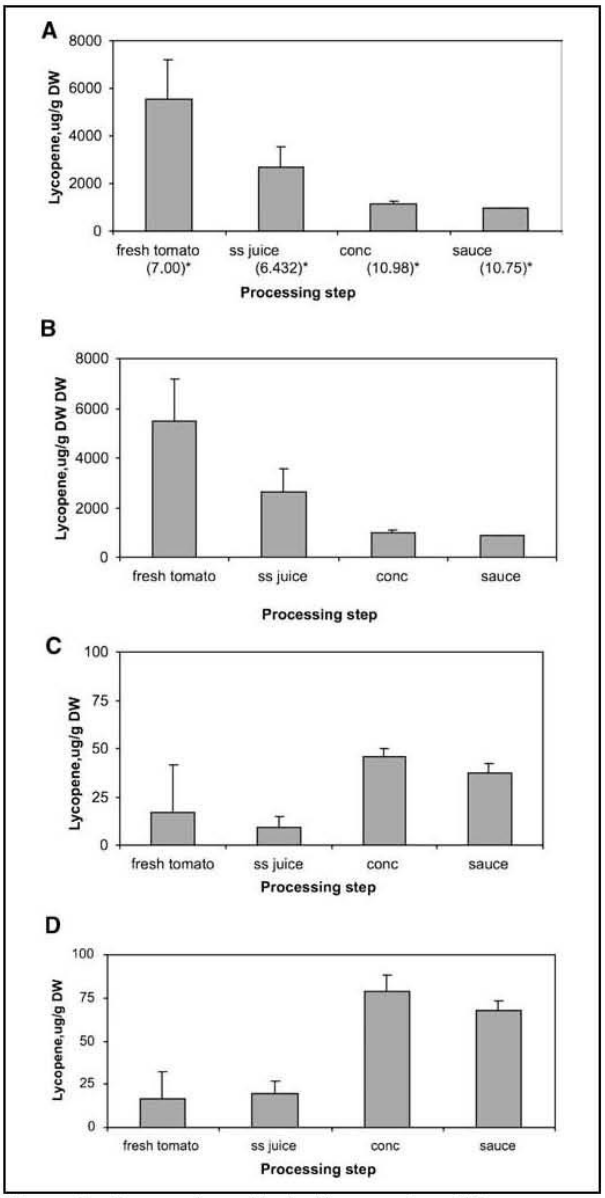


**Figure 3—Processing affects the carotenoid-isomer concentrations of Tangerine tomatoes during processing. A: Total lycopene concentrations, B: *Tetra-cis* lycopene concentrations, C: *Trans*-lycopene concentrations, and D: Other *cis*-lycopene isomer concentrations. SS juice = single strength juice; conc = concentrate. Numbers in parentheses represent percent solids.**

After processing into tomato sauce, the carotenoid profile of the tomato product is altered, as shown in Figure 2B. The total amount of lycopene decreased considerably, especially after the 1st step in the procedure (see Figure 3A, Table 1), which consisted of heating sliced tomatoes in a microwave oven, placing in chilled storage for several hours, and juicing. This was followed by concentrating the juice by further heating on a stove top to increase soluble solids content, cooling, adjusting pH, and canning and sterilizing the resulting sauce. The change in isomer profile seen in Figure 2A and B then depicts the degree of isomerization that occurred during processing.

## Carotenoid isomer composition

Figure 3 and Table 1 also show changes in each of the measured stereoisomers of lycopene (*tetra-cis, trans,* and combined other-*cis* isomers) at various stages throughout processing. A continuous decline in total lycopene is observed, with the greatest drop occurring initially during the 1st step, which included heating, cooling, and juicing. Subsequent steps caused much smaller losses in lycopene content. During this step, a large decrease in concentration of the *tetra-cis* isomer of lycopene occurred, accompanied by a smaller decrease in the all-*trans* isomer (Figure 3B and C). However, the actual amount of the *trans* isomer of lycopene in raw Tangerine tomato fruit was very small (Table 1). Whole raw tomato contained approximately 17 $\mu$g/g DW *trans* lycopene, compared to 5500 $\mu$g/g DW of the *tetra-cis* isomer. The amount of other *cis*-lycopene isomers increased somewhat during this 1st step (Figure 3D, Table 1).

Lycopene isomerization, on the other hand, occurs primarily during subsequent steps. Note that the amount of *tetra-cis* lycopene continued to decrease after the 1st step (Figure 3B), accompanied by a large increase in the amount of *trans*-lycopene (Figure 3C) and other *cis*-lycopene isomers, as well as the number of the latter (Figure 3D). After that, even through the canning and sterilization processes, only small fluctuations in the distribution of isomers occurred. These observations are consistent with Hackett and others data (2004). These authors report that at storage temperatures of 25 and 50 °C, *tetra-cis* lycopene from Tangerine tomato oleoresin degraded without isomerization, whereas at 75 and 100 °C, isomerization to *trans* and other *cis* forms of lycopene occurred along with their degradation products. The 1st processing step, consisting of heating, cooling, and juicing, showed primarily degradation with very little isomerization. The temperatures obtained during microwave heating were overall lower than those temperatures during juice concentration, where isomerization occurred. Measured concentrations along with standard deviations of the tomato products of Tangerine tomatoes at various stages of processing described in this paper are given in Table 1.

**Table 1—Lycopene-isomer content in Tangerine tomatoes during processing ($\mu$g/g DW)**

| Isomer | Fresh tomato | SS juice | Concentrate | Sauce |
|---|---|---|---|---|
| *Tetra-cis* | 5491.78 | 2642.00 | 1002.98 | 849.73 |
| s.d. | 1707.47 | 900.12 | 102.81 | 28.96 |
| *Trans* | 17.21 | 9.21 | 45.78 | 37.08 |
| s.d. | 24.46 | 5.27 | 3.93 | 4.97 |
| Other *cis* | 16.35 | 19.66 | 78.84 | 68.03 |
| s.d. | 16.10 | 6.84 | 9.10 | 5.38 |
| Total | 5525.33 | 2664.33 | 1127.60 | 954.84 |
| s.d. | 1696.82 | 902.86 | 113.06 | 38.78 |

Data provided in the study by Unlu and others (2007) are difficult to compare with our data since the objective of their study was to compare the bioavailability of Tangerine tomatoes made into tomato sauce with that made from high $\beta$-carotene tomatoes, and few details on tomato processing are given. Their method of processing tomatoes into sauce also differs. In their study, tomatoes were processed into canned juice, but only temperature and heating time are given. Sauce was produced by concentrating juice on a rotary evaporator under vacuum at 60 °C. Their data show considerable isomerization of *tetra-cis* lycopene, as do ours, along with degradation. However, concentrations of lycopene isomers in whole tomatoes and sauce are given as mg/100 g (wet weight). Estimates of degradation can be made, but only an approximate concentration of whole tomatoes to sauce is provided

Because lycopene is such a valuable and beneficial compound to human health, it is important to reduce degradative losses of the compound during processing. As seen in Figure 3A, the greatest loss occurs during the 1st step, which includes heating, cooling, and juicing. The purpose of the heating step is to inactivate cell-wall degrading enzymes, polygalacturonase (PG) and pectin methylesterase (PME). These enzymes degrade pectin in the cell walls and tissues, resulting in decreased viscosity of the product. In preparation of tomato sauce, a hot break process is preferred over a cool break process because rapid enzyme inactivation is achieved, which produces thicker-bodied juice that also contains desirable flavor compounds characteristic of cooked tomatoes. The enzymes become inactivated only at a temperature of about 82 °C. It is recommended that this temperature be maintained for at least 15 s (Gould 1992). Using a microwave process for this purpose is advantageous because high heat can be attained very quickly.

However, in this case, it seems that factor(s) involved in this 1st step of processing resulted in an approximately 52% loss of total lycopene, although an increase (about 20%) in other *cis*-lycopene isomers also occurred (see Table 1 and 2). Nguyen and others (2001) reported that heating both *trans* lycopene (in red) and prolycopene (*tetra-cis* lycopene) (in Tangerine tomatoes) at 100 °C for 30 min in water or in a mixture of water: olive oil (80:20) resulted in very little isomerization. The reasons given for the low degree of isomerization of the all-*trans* isomer was its tendency to form layered aggregates because of its linear shape. These aggregates might contribute to a resistance to further structural changes. It was suggested that the increased length of the linear *trans* molecule might also contribute to its stability in terms of activation energies, whereas *tetra-cis* lycopene is shorter because of its 4 *cis* double bonds, and 2 of these are hindered, making stereochemical interconversion less likely. However, Hackett and others (2004) in examining thermal stability and isomerization of lycopenes in different tomato oleoresins reported that *tetra*-cis lycopene present in oleoresin from Tangerine tomatoes degraded more rapidly compared to *trans* lycopene in oleoresins prepared from other tomato varieties. It seems then that the general conclusion from data from Schwartz's laboratory (2001) is that the *trans*-lycopene isomer is relatively stable to isomerization at temperatures between 50 and 100°C. That conclusion is also supported by our own data from subsequent experiments (see below).

To compare lycopene isomerization and degradation in Tangerine compared with red tomatoes, we obtained samples of fresh and microwave-heated and juiced red tomatoes from the pilot plant at the Univ. of California in Davis, samples taken as part of an ongoing study on tomato varieties conducted by the Dept. of Food Science and Technology. Three varieties of red tomato were sampled and their lycopene-isomer concentrations were measured. These data are shown in Table 2. Also included in Table 2 are data obtained using fresh market tomatoes treated similarly. We categorized these as low carotenoid (LC) and medium carotenoid (MC) and compared lycopene-isomer concentrations in fresh and microwave-heated tomatoes in our laboratory to simulate conditions in the pilot plant. Our data show that equivalent exposures to microwave heating of Tangerine and several varieties of red tomatoes resulted in greater loss of *tetra-cis* lycopene in Tangerine tomatoes (51.8% compared with 6.6% to 48% loss of the all-*trans* lycopene from red tomatoes, depending upon the tomato variety). The data also show that the all-*trans* lycopene in some of the varieties of red tomato is degraded to almost the same extent as the *tetra-cis* isomer in Tangerine tomatoes. Our data support the conclusion from Schwartz's lab (2001) that *tetra-cis* lycopene in Tangerine tomatoes is more susceptible to degradation than the all-*trans* lycopene, which is the major form found in red tomatoes.

In addition to heating, the lycopene content in the 1st sample taken could have been affected by the cooling and juicing processes, which involved considerable periods of time and exposure to air and light. The juicing process involves physical

**Table 2—Lycopene-isomer content in Tangerine and red tomato varieties before and after microwave heating ($\mu$g/g DW)**

| Tomato | *Tetra-cis* | | | *Trans-cis* | | | *Other-cis* | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| variety[a] | Fresh | pMWH[b] | % Initial | Fresh | pMWH | % Initial | Fresh | pMWH | % Initial | Fresh | pMWH | % Initial |
| Tangerine | 5492 | 2642 | 48.1 | 17.2 | 9.2 | 53.5 | 16.4 | 19.7 | 120.2 | 5525 | 2664 | 48.2 |
| s. d. | 1707.5 | 900.1 | 24.5 | 5.3 | | | 16.1 | 6.8 | | 1697 | 903 | |
| UCD-1 | | | | 2427 | 2001 | 82.4 | 123.7 | 153.5 | 154.1 | 2551 | 2155 | 84.5 |
| s. d. | | | | 83.8 | 161.1 | | 10.3 | 15.0 | | 94.0 | 176.2 | |
| UCD-2 | | | | 4266 | 2214 | 51.9 | 322 | 171 | 53.1 | 4588 | 2385 | 52.0 |
| s. d. | | | | 406.1 | 248 | | 29.5 | 13.8 | | 406.1 | 261.7 | |
| UCD-3 | | | | 2137 | 1890 | 88.5 | 130.5 | 127.3 | 97.6 | 2267 | 2017 | 89.0 |
| s. d. | | | | 110 | 19 | | 1.14 | 5.9 | | 111.6 | 24.6 | |
| C-LC | | | | 471 | 325 | 68.9 | 87.3 | 61.0 | 70.3 | 556 | 386 | 69.4 |
| s. d. | | | | 11.3 | 22.7 | | 10.5 | 2.26 | | 10.8 | 28.8 | |
| C-MC | | | | 953 | 863 | 90.6 | 73.9 | 95.7 | 129.5 | 1026 | 959 | 93.4 |
| s. d. | | | | 240 | 37.8 | | 23.0 | 10.6 | | 263 | 148 | |

[a]Tangerine tomatoes were subjected to the pilot plant juicing procedure before lycopene was analyzed. The others were frozen, and samples were analyzed later. UCD tomatoes were those being tested at the Univ. of California Davis; CLC = commercial low-carotenoid; and CMC = commercial medium-carotenoid tomatoes.
[b]pMWH = post-microwave heating.

damage to tomato tissues, and the finisher removes most of the tomato pulp from the juice. Judging from appearance, significant amounts of lycopene were trapped in the tomato matrix and discarded. Investigations on losses from the juicing process of apples (Lu and Foo 1997; Price and others 1999) show that valuable phenolics and flavonoids of the fruit were trapped in the pomace, which was normally discarded. Gerard and Roberts (2004) showed that microwave heating of apple mash could improve juice yield and quality. It would be desirable in the future to determine factors such as optimal time/temperature for pectic enzyme inactivation and release of maximal lycopene concentrations and other carotenoids into the juice, and lycopene losses during of exposure to light and temperature at various steps in the processing procedure to improve the quality of tomato products. We are currently conducting experiments to obtain such information.

## Conclusions

Processing Tangerine tomatoes resulted in several important changes in carotenoid concentration and lycopene-isomer profile. Lycopene in fresh, uncooked Tangerine tomatoes is primarily in the form of the *tetra-cis* isomer. During the 1st steps of processing, which included slicing, heating, cooling, and then juicing, a large amount of degradation of the *tetra-cis* lycopene isomer occurred along with a small amount of isomerization to other *cis*-lycopene isomers. Our results are consistent with those from Schwartz's laboratory (Nguyen and others 2001; Hackett and others 2004; Unlu and others 2007), showing that the *tetra-cis*-lycopene isomer is less stable and more easily degraded compared with the *trans*-lycopene isomer, which is the prevalent form in red tomatoes. Thus, heating, prolonged exposure to light and oxygen, and juicing are the likely sources of transformation and degradation.

In subsequent steps, consisting mostly of heating to concentrate the juice to form sauce, degradation is much less, but isomerization increases. This again is consistent with the work of Hackett and others (2004) and Unlu and others (2007). We observed an increase in *trans*-lycopene and a greater increase in other *cis* isomers of lycopene. *Cis*-lycopene isomers have been shown to be more bioavailable than the *trans* isomer, indicating that they are more efficiently absorbed and therefore deliver lycopene into the plasma more effectively. This might be interpreted to mean that *cis* isomers of lycopene are more beneficial and therefore more valuable to human health than the *trans* isomer. Therefore, it seems prudent to examine the effects of each step in the processing of tomatoes to optimize the health benefits of tomato products.

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