Processing Effects on Lycopene Content and Antioxidant Activity of Tomatoes

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Consumption of tomato products has been associated with decreased risk of some cancer types, and the tomato antioxidant, lycopene, is thought to play an important role in the observed health effects. In this study, four carotenoids, *trans*-lycopene, phytofluene, phytoene, and ζ-carotene, were quantified in tomato products. Samples of raw tomatoes, tomato juice after hot break scalder, and final paste were obtained from two different processing plants over two years. Comparison of carotenoid levels throughout processing indicated that lycopene losses during processing of tomatoes into final paste (25−30 °Brix) ranged from 9 to 28%. The initial Brix level of the raw tomatoes appeared to influence the amount of lycopene loss that occurred, possibly due to the differences in processing time required to achieve the final desired Brix level of the paste. In general, no consistent changes in the other carotenoids were observed as a function of processing. The antioxidant activity of fresh tomatoes, tomato paste, and three fractions obtained from these products (i.e., aqueous, methanol, and hexane fractions) was also determined. In both a free radical quenching assay and a singlet oxygen quenching assay, significant antioxidant activity was found in both the hexane fraction (containing lycopene) and the methanol fraction, which contained the phenolic antioxidants caffeic and chlorogenic acid. The results suggest that in addition to lycopene, polyphenols in tomatoes may also be important in conferring protective antioxidative effects.

Keywords: *Carotenoids; phytofluene; phytoene; ζ-carotene; tomato paste*

INTRODUCTION

Numerous epidemiology studies have shown an inverse association between lycopene intake or serum lycopene values and cancers of the prostate, pancreas, and possibly stomach (reviewed in refs *1* and *2*). The major dietary sources of lycopene are fresh tomatoes and tomato products such as juice, paste, puree, and sauce (*3*). Other quantifiable carotenoids in these products include phytoene, phytofluene, ζ-carotene, neurosporene, γ-carotene, and β-carotene, but their concentrations are significantly lower than that of lycopene (*3*).

Giovannucci and co-workers have observed that consumption of processed tomato products, but not tomato juice, was associated epidemiologically with a decreased risk of prostate cancer (*4*, *5*). Possible reasons for this observation are unclear. Stahl and Sies (*6*) have suggested that uptake of lycopene is greater from heat-processed juice than from unprocessed tomato juice, although a recent study by Rao and Agarwal (*7*) showed that lycopene from both tomato juice and tomato sauce was readily absorbed. Wang et al. (*8*) have observed that heat-processed tomato juice had a much higher antioxidant activity than fresh tomatoes; the reason for the increase in antioxidant activity as a function of processing was not evaluated.

In general, studies on lycopene content and antioxidant activity of tomatoes have not systematically followed changes throughout processing. For example, in many cases it is not known if observed changes are due to improved extraction during the processing or to the actual effects of the heat treatment (i.e., production or destruction of other antioxidants, etc.). In other cases, the varieties of the fresh tomatoes and the processed products were different or the processing conditions did not fully simulate commercial processing conditions. Therefore, the overall goal of this project was to evaluate the effect of processing on the lycopene content and antioxidant activity of tomatoes. Sampling and processing were conducted in commercial processing facilities over two growing seasons.

MATERIALS AND METHODS

Sampling and Processing Conditions. Tomato samples were obtained from two different processing plants during 1998 and 1999. In 1998, samples were taken from plant A on September 15 and from plant B on September 23. During the 1999 season, sampling was conducted on September 1 and 7 from plants A and B, respectively. Tomatoes in these samples represented a mixture of varieties harvested in the surrounding areas of northern California. The predominant variety was BOS 3155.

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Three sampling points were monitored: (a) raw tomatoes from flume (~1500 g sample); (b) juice after hot break scalder (with seeds and skins) (~2000 g sample); and (c) final paste (~28 °Brix; 5000 g sample). Three separate samples were obtained from point a at 0.5 h intervals. Samplings from points b and c were subsequently delayed by an appropriate length of time (~0.25 and 3.0 h, respectively) with respect to point a to allow for transit through the processing line so that a sample from the same "batch" of tomatoes could be obtained at all sampling points. Following sampling, all products were stored on ice and transported to the laboratory. Fresh tomatoes were homogenized and extracted within 24 h. The fresh tomato extracts were stored at −80 °C until HPLC analysis, whereas all processed tomato products were stored at −20 °C until extracted or subjected to antioxidant analysis.

Soluble Solids. Homogenized fresh tomatoes and hot break juice were filtered to produce a clear supernatant. The soluble solids content was determined using a Bellingham and Stanley Ltd. (Kent, U.K.) model RFM81 automatic refractometer. To determine soluble solids of tomato paste, the paste was first centrifuged for 10 min at 120000 rpm (Beckman Optima TLX Ultra centrifuge; Beckman Coulter, Inc., Fullerton, CA). A Leica Mark II Abbe refractometer (Leica Microsystems Inc., Buffalo, NY) was used to measure the soluble solids of the resulting supernatant.

Analysis of Lycopene. Extraction and HPLC analysis of lycopene and related carotenoids was based on the method of Tonucci et al. (*9*). All analyses were done in duplicate. Tomatoes (~150 g), hot break juice (~150 g), or tomato paste (~50 g) was combined with Celite (10 wt %; Fisher Scientific, Fair Lawn, NJ), magnesium carbonate (10 wt %; Sigma, St. Louis, MO), and 10 mL of a 0.2 mg/mL β-apo-8′-carotenal (Fluka Chemical Corp., Milwaukee, WI) internal standard solution (prepared in methylene chloride) in a beaker. The resulting mixture was combined with 250 mL of tetrahydrofuran (THF; certified grade, stabilized with 0.025% BHT; Fisher Scientific) and mixed for 15 min with a Polytron model PT3100 homogenizer (Brinkmann Instruments, Inc., Westbury, NY). The mixture was chilled in an ice bath during the homogenization procedure. The homogenate was filtered through Whatman No. 1 filter paper (90 mm; Whatman Inc., Clifton, NJ) on a Büchner funnel. The solid material was extracted a minimum of two more times (extraction was repeated until the filtrate and solid were colorless) with 250 mL aliquots of THF using the above procedure. The combined THF extract was concentrated to about one-third of the original volume under vacuum (Precision model D25 vacuum pump; Precision Scientific Group, Chicago, IL) at room temperature (22 °C) on a rotary evaporator. The concentrated extract was then partitioned into 250 mL of methylene chloride [HPLC grade, stabilized with 0.025% BHT (Fisher Scientific) and 0.1% *N*,*N*′-diisopropylethylamine; Aldrich, Milwaukee, WI] and 150 mL of aqueous saturated sodium chloride solution. After mixing, the water layer was removed and the solvent layer washed three more times with aqueous saturated sodium chloride solution (150 mL aliquots). The aqueous layer was then washed three times with 200 mL aliquots of a methylene chloride/THF (50:50 v/v) mixture to remove color from the water. The solvent layers were combined and dried for ~12 h on sodium sulfate (~20 wt %) at 0 °C. The solution was allowed to come to room temperature and was then inspected for the presence of water. Additional sodium sulfate was added (80 g) if the solution was not free of water. The solution was shaken and allowed to stand until clear. The dry methylene chloride/THF extract was filtered (Whatman No. 42 filter paper) and concentrated to 10 mL on a rotary evaporator as described above. The concentrate was filtered through a 0.45 μm syringe filter and brought to 50.0 mL with methylene chloride (stabilized with 0.025% BHT and 0.1% *N*,*N*′-diisopropylethylamine) in a volumetric flask. Samples were stored at −80 °C until HPLC analysis. Prior to HPLC analysis, 100 μL of extract was diluted with 900 μL of a mixture of acetonitrile/methanol/dichloromethane/hexane (40:20:20:20 v/v) and filtered through a 0.45 μm syringe filter. A 20 μL aliquot was injected onto the HPLC.

The HPLC system consisted of a Hewlett-Packard 1050 quaternary pump equipped with a manual injector with a 20 μL sample loop (model 7125, Rheodyne L.P., Rohnert Park, CA) and a Hewlett-Packard 1040M series II diode array detector. The Rainin Dynamax C_{18} column, 5 mm, 25 cm × 4.6 mm i.d. (Varian Associates, Walnut Creek, CA), was coupled to a guard column (Rainin Dynamax) containing the same packing material. The initial mobile phase consisted of acetonitrile (85%), methanol (10%), dichloromethane (2.5%), and hexane (2.5%) at a flow rate of 0.8 mL/min for 10 min. This was followed by a linear gradient for the next 30 min (total run time was 40 min) to a final solvent composition of acetonitrile (45%), methanol (10%), dichloromethane (22.5%), and hexane (22.5%). The diode array detector was set to simultaneously monitor at 470, 455, 400, 350, and 286 nm.

Four carotenoids were identified and quantified: *trans*-lycopene, ζ-carotene (*cis* + *trans*), phytofluene (*cis* + *trans*), and phytoene (*cis* + *trans*). The identities of *trans*-lycopene and phytofluene were confirmed by comparison of retention times and UV spectra with those of authentic standards obtained from Hoffmann-La Roche Ltd. (Basel, Switzerland). Peak identities of phytoene and ζ-carotene (*cis* + *trans*) were based on comparison of retention times and UV spectra with those reported in the literature.

Lycopene concentration was corrected for recovery of the internal standard, β-apo-8′-carotenal, and absolute amounts were determined using authentic lycopene standards. All other carotenoid concentrations were reported relative to the weight equivalent of the internal standard (IS).

Antioxidant Activity. Three fractions (aqueous, methanol, and hexane fractions) were prepared from fresh tomatoes and tomato paste and used in the antioxidant assays. To prepare the fractions, tomatoes (100 g) were first blended for 10 min under a nitrogen atmosphere in a Waring blender to yield a homogenate. Tomato paste (50 g) or the fresh homogenate was then centrifuged at 3000 rpm for 15 min (1 h for paste) at 10 °C. Vials were topped with nitrogen gas prior to centrifugation to limit oxidation. The aqueous supernatant was used directly in the antioxidant assay. The remaining pulp and 100 mL of methanol were combined in the blender and blended for 10 min under nitrogen atmosphere. The mixture was centrifuged as described previously, and the methanol supernatant was used directly in the antioxidant assay. The remaining pulp and 100 mL of hexane were combined in the blender and blended for 10 min under nitrogen atmosphere. Following centrifugation, as previously described, the hexane supernatant was used directly in the antioxidant assay.

The antioxidant activity of the fractions from fresh and processed tomatoes was determined using two methods. Free radical quenching activity was measured in a phosphatidylcholine liposome solution similar to that described by Huang and Frankel (*10*) and Huang et al. (*11*). Phosphatidylcholine (Sigma Chemical Co.) was dissolved in water with constant stirring for ~45 min to give a concentration of 8 mg/mL. The mixture was then sonicated for 5 min with a sonicating probe (Sonic Dismembrator 60, Fisher Scientific) at half power to yield a liposome solution. An aliquot (100 μL) of a previously prepared tomato fraction was placed in a 20 mL glass screw-top vial, and 10 mL of the liposome solution was added. The vials were again sonicated for 5 min to disperse the tomato fraction into the solution. Oxidation was initiated by adding 10 μL of a 2 mg/mL cupric acetate solution (prepared in methanol). The samples were held in a water bath at 37 °C, and the reaction rate was monitored by following the formation of conjugated dienes at 234 nm (Milton Roy, Spectronic 601, Rochester, NY). Prior to spectral measurement 100 μL of sample was diluted with 5 mL of methanol. All samples were replicated a minimum of four times. The antioxidant activity of a 15 mM solution of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid; Aldrich) was also determined simultaneously as a positive control.

Singlet oxygen quenching activity was monitored in a linoleic acid emulsion using *p*-dimethylnaphthalene endoperoxide (*12*, *13*). Endoperoxides are readily synthesized from their parent compounds by photo-oxidation. In this case, 1,4-

Table 1. Mean Carotenoid Levels ± SD in Tomato Extracts (Milligrams per 100 g of Juice or Paste) Determined by HPLC[a]

sample	°Brix	recovery of IS (%)	*trans*-lycopene	phytofluene (*cis* + *trans*)	phytoene (*cis* + *trans*)	ζ-carotene (*cis* + *trans*)
			1998			
plant A paste	25	94.17 ± 0.98	82.35 ± 3.54	4.14 ± 0.12	3.26 ± 0.13	1.02 ± 0.02
plant B paste	30	94.17 ± 2.64	82.90 ± 3.13	5.39 ± 0.16	4.48 ± 0.16	1.71 ± 0.18
plant A hot break	5.4	92.33 ± 4.63	19.46 ± 0.86	0.92 ± 0.06	0.66 ± 0.09	0.18 ± 0.01
plant B hot break	5.5	88.83 ± 4.36	18.19 ± 1.83	1.18 ± 0.11	0.84 ± 0.15	0.30 ± 0.05
plant A fresh	5.4	75.83 ± 6.55	17.34 ± 5.07	1.34 ± 0.36	0.86 ± 0.42	0.27 ± 0.06
plant B fresh	5.5	91.17 ± 7.03	17.32 ± 1.53	1.26 ± 0.13	1.16 ± 0.06	0.29 ± 0.05
			1999			
plant A paste	25	87.50 ± 4.64	86.85 ± 10.62	5.02 ± 0.23	3.64 ± 0.28	1.13 ± 0.1
plant B paste	30	86.00 ± 3.58	83.80 ± 3.88	5.06 ± 0.11	3.50 ± 0.17	1.28 ± 0.15
plant A hot break	4.9	82.33 ± 4.59	22.76 ± 1.12	1.32 ± 0.09	0.94 ± 0.12	0.27 ± 0.02
plant B hot break	5.4	84.50 ± 4.28	16.87 ± 0.38	0.95 ± 0.07	0.68 ± 0.05	0.25 ± 0.01
plant A fresh	4.9	85.00 ± 4.65	23.65 ± 2.22	0.88 ± 0.17	0.81 ± 0.14	0.15 ± 0.01
plant B fresh	6.0	86.17 ± 3.97	20.14 ± 1.85	0.89 ± 0.19	0.77 ± 0.17	0.17 ± 0.03

[a] Lycopene and phytofluene were quantified with authentic standards; phytoene and ζ-carotene were quantified by weight equivalent of β-apo-8′-carotenal (internal standard).

dimethylnaphthalene (Sigma) was dissolved in hexane and oxidized to the endoperoxide in a photochamber with a tungsten filament. Methylene blue (Sigma) was used as the "sensitizer", and compressed air (Puritan Bennet, Lenexa, KS) was bubbled through the chamber as a source of oxygen. The endoperoxide was purified on a silica column and crystallized under a stream of nitrogen gas (Puritan Bennet). All of this was performed at 4 °C to prevent thermolysis. The endoperoxide (1 mM) was added to a 60 mM solution of linoleic acid in hexane/ethanol (1:1 v/v), and 10 mL of this solution was placed in a 20 mL vial. Aliquots (100 μL) of the tomato fractions were added, and oxidation was initiated by placing the vial in a 37 °C water bath. Formation of conjugated dienes was monitored at 234 nm. All assays were replicated a minimum of four times.

Results for all antioxidant assays were expressed as percent inhibition of conjugated diene formation as compared to a control solution that did not contain any antioxidants (*14*). Percent inhibition was determined 35 h following initiation of oxidation for the free radical antioxidant assays and 5 h postinitiation for the singlet oxygen assays.

Ascorbic Acid Analysis. Tomato samples were sent frozen, on dry ice, to The National Food Laboratory, Inc., Dublin, CA, for HPLC analysis of ascorbic acid (*15*).

Statistical Analyses. Means and standard deviations for replicate analyses were calculated for all samples. Sample means were compared using Student's *t*-test (*16*) where appropriate.

RESULTS AND DISCUSSION

Analysis of Carotenoids. Four carotenoids in fresh and processed tomatoes were quantified: *trans*-lycopene, ζ-carotene (*cis* + *trans*), phytofluene (*cis* + *trans*), and phytoene (*cis* + *trans*). Overall recovery of the internal standard (β-apo-8′-carotenal) was excellent, ranging from 82 to 95% for hot break juice and paste (Table 1). Internal standard recovery for the fresh tomatoes was slightly lower (76−91%) and more variable for replicate analyses, particularly during the 1998 season. The reason for this lower recovery and higher variability is unknown but may be due to unfamiliarity with the analysis procedure for the initial fresh tomato analyses during the 1998 season and the less homogeneous nature of the fresh tomato matrix (compared to hot break juice and paste). The precision (% CV) for replicate assays was generally <6% for all samples (except fresh tomatoes during 1998).

Concentrations of the four carotenoids in fresh tomatoes, hot break juice, and final paste at the two processing plants during 1998 and 1999 are given in Table 1. As expected, concentrations of all carotenoids were higher in paste than in fresh tomatoes and hot break juice. In a review of carotenoid content of foods, Mangels et al. (*17*) calculated average lycopene values of 31000 and 85000 μg/100 g for fresh tomatoes and paste, respectively. Measured lycopene values in fresh tomatoes in this study were slightly lower than the average value reported by Mangels et al.; however, concentrations were consistent between processing plants and between the two years. Lycopene concentrations in the paste were in agreement with average values reported by Mangels et al. and were consistent among all samples.

Effects of Processing on Carotenoid Concentrations. To compare processing effects, carotenoid levels of the fresh and hot break juices were corrected to the Brix levels (i.e., soluble solids) of the final paste (Table 2). No consistent changes in lycopene levels were observed as the fresh tomatoes were processed into hot break juice. However, statistically significant decreases in lycopene levels of ∼9−28% occurred as the tomatoes were processed into paste (Table 2). The greatest loss (∼28%) occurred at plant A in 1999 and may be related to the slightly lower Brix levels for the fresh tomatoes and hot break juice (4.9 °Brix) requiring a longer processing time to achieve the final Brix value of the paste. The smallest losses (<8.6%) occurred at plant A during the 1998 and were associated with the smallest fold change in Brix level during processing (4.6-fold increase in Brix from fresh/hot break juice to paste compared to >5-fold increase for the other samples). Losses at plant B were consistent between both years, ranging from 11 to 17% and averaging 14%. No consistent changes in the other carotenoids were observed and, in general, levels of these carotenoids were not affected by processing (Tables 1 and 2).

Kinetic studies in model systems (pure lycopene in safflower oil) have shown that lycopene is highly susceptible to oxidative and thermal degradation with a reaction rate approximately double that of other carotenoids studied (β-carotene and lutein) (*18*). However, Abushita et al. (*19*) observed no change in lycopene concentration as fresh tomatoes were processed into paste in a commercial processing facility. Nguyen and Schwartz (*20*) also suggested that in tomato products, lycopene was relatively resistant to degradation, including thermally induced *trans*−*cis* isomerization reactions.

Table 2. Mean Carotenoid Levels ± SD in Tomato Extracts (Milligrams per 100 g as Paste) Corrected to °Brix Level of Final Paste[a]

	1998			1999		
	fresh tomatoes	hot break juice	paste	fresh tomatoes	hot break juice	paste
			Plant A (Corrected to 25 °Brix)			
trans-lycopene	80.27 ± 23.49^{NS}	90.11 ± 3.98* (8.6%)	82.35 ± 3.54	120.67 ± 11.34** (28.0%)	116.13 ± 5.70*** (25.21%)	86.85 ± 10.62
phytofluene (*cis* + *trans*)	6.20 ± 1.67	4.27 ± 0.29	4.14 ± 0.12	4.50 ± 0.88	6.78 ± 0.46	5.02 ± 0.23
phytoene (*cis* + *trans*)	3.97 ± 1.9	3.04 ± 0.40	3.26 ± 0.13	4.12 ± 0.72	4.8 ± 0.6	3.64 ± 0.28
ζ-carotene (*cis* + *trans*)	1.24 ± 0.28	0.84 ± 0.02	1.02 ± 0.02	0.76 ± 0.07	1.38 ± 0.09	1.13 ± 0.1
			Plant B (Corrected to 30 °Brix)			
trans-lycopene	94.48 ± 8.34* (12.26%)	99.24 ± 9.97** (16.47%)	82.90 ± 3.13	100.71 ± 9.26*** (16.79%)	93.73 ± 2.13* (10.59%)	83.80 ± 3.88
phytofluene (*cis* + *trans*)	6.85 ± 0.69	6.45 ± 0.65	5.39 ± 0.16	4.47 ± 0.96	5.29 ± 0.37	5.06 ± 0.11
phytoene (*cis* + *trans*)	6.33 ± 0.35	4.56 ± 0.84	4.48 ± 0.16	3.85 ± 0.83	3.76 ± 0.25	3.50 ± 0.17
ζ-carotene (*cis* + *trans*)	1.58 ± 0.26	1.62 ± 0.28	1.71 ± 0.18	0.84 ± 0.13	1.39 ± 0.06	1.28 ± 0.15

[a]Value in parentheses is percent change in concentration of paste relative to fresh or hot break. ^{NS}, not significantly different from paste at $p > 0.05$, two-tailed, paired *t* test. *, significantly different from paste at $p < 0.05$, two-tailed, paired *t* test. **, significantly different from paste at $p < 0.01$, two-tailed, paired *t* test. ***, significantly different from paste at $p < 0.001$, two-tailed, paired *t* test.

In our study, significant losses in lycopene were observed, and greater losses appeared to be associated with conditions requiring more extensive processing. However, overall losses were <30% and were small compared to those observed for pure lycopene in model systems under similar conditions.

Reasons for the apparent stability of lycopene in tomato products are unclear. Abushita et al. (*19*) observed that ascorbic acid, tocopherols, and β-carotene levels decreased as a function of thermal processing. Similarly, we observed a decrease in ascorbic acid content from 10 to 12 mg/100 g in the juice to 2 mg/100 g in the paste. Whether these antioxidants or other components that are present in tomatoes play a role in preventing the degradation of lycopene is unclear. Further studies are needed to fully understand the interrelated effects of heat treatments on the stability of the carotenoids and other antioxidants.

Antioxidant Activity. The conjugated double-bond system of lycopene confers strong antioxidant activity including the ability to quench singlet oxygen and peroxyl radicals. The singlet oxygen quenching activity of lycopene has been shown to be greater than that for other carotenoids, including β-carotene (*2*; reviewed in ref *21*). In vivo, lycopene consumption has been associated with decreased levels of serum lipid peroxidation and low-density lipid (LDL) peroxidation (*7*, *22*).

We evaluated both the free radical and singlet oxygen quenching activities of the tomato products. Overall reproducibility of the free radical quenching assay was excellent, with a coefficient of variation for replicate analyses of a control sample being <10% over six different days of analysis ($n = 24$). However, when juice or paste was used directly in the assays, large variabilities were observed, particularly for the paste. This was thought to be due to the presence of particulate matter in the samples. To eliminate the variability associated with particulates in the samples, the tomatoes were centrifuged to yield an aqueous supernatant and then extracted successively with methanol and hexane. The antioxidant activity of the three fractions was then evaluated.

Antioxidant activity was observed in each of the three fractions, and tomato paste had a greater antioxidant activity in all fractions than fresh tomatoes (Table 3). In comparison, 15 mM Trolox showed a free radical quenching activity of 52% compared to the control; all fractions except the methanol fraction from paste exhibited activities lower than that of 15 mM Trolox in this assay.

Table 3. Percent Inhibition of Lipid Peroxidation As Measured by Conjugated Diene Formation for Different Fractions Obtained from Tomatoes

	% inhibition compared to control ($n = 4$)		
	aqueous	methanol	hexane
free radical antioxidant activity			
fresh	10.9	5.2	18.2
paste	25.2	64.8	28.4
singlet oxygen quenching activity			
paste	not measured	9.3	4.7

In fresh tomatoes, the lycopene-containing hexane fraction had the greatest activity. The activity of the paste was greater than that of the fresh juice; however, when the activity of the fresh juice was corrected to a similar solids basis as the paste (30 °Brix) the observed activity was lower than expected, indicating loss in activity as a result of processing. This is consistent with decreases in lycopene concentration discussed previously.

In paste, the methanol fraction contained the greatest activity. When the activity of the fresh juice was corrected to a similar solids basis as the paste (30 °Brix), the activity of the paste was greater than expected as a result of the processing treatments. Similar increases in antioxidant activity were observed by Wang et al. (*8*) in heat-processed tomato juice and grape juice compared with fresh products. Reasons for the increase in activity in these studies are unknown, but it may be at least partially explained by the production of new antioxidants during processing. For example, a recent study by Stewart et al. (*23*) indicated that the free, nonconjugated forms of two polyphenols, quercetin and kaempferol, increased during thermal processing of tomatoes. Whether the free forms of polyphenols have greater antioxidant activity than the conjugated forms is not clear. Lavelli et al. (*24*) also observed a slightly higher concentration of total phenols in commercial tomato paste compared with fresh tomatoes. An HPLC analysis of the methanol phase used in our study identified two polyphenols as major constituents, caffeic and chlorogenic acids, consistent with literature reports (reviewed in ref *25*). However, the effect of processing on changes in these constituents was not evaluated. The results of this and other studies point to the critical need for future studies that will fully evaluate changes in

levels of all polyphenol classes as well as changes in the antioxidant activity of these compounds as a function of processing treatments in tomatoes.

Summary. Thermal processing of tomatoes into paste can result in decreases in lycopene concentration of 9−28%. Longer processing times, required to achieve the desired final solids levels, may be associated with increased losses. In general, however, lycopene in tomatoes is relatively resistant to degradation compared to pure lycopene in model systems. Other constituents, including tocopherols, ascorbic acid, and phenolic antioxidants, may help to stabilize lycopene during processing; however, further studies are needed to evaluate these effects. Changes in the antioxidant activity of tomato products are complex and depend on the specific compounds being studied. Initial results suggest that losses in antioxidant activity associated with decreases in lycopene concentration during processing may be accompanied by increases in antioxidant activity of other components, particularly polyphenolics. Therefore, further studies characterizing changes in polyphenol content and antioxidant activity during thermal processing will be critical to fully understand the role that fresh and processed foods in the diet may play in preventing human disease.

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