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Effects of Cooking Conditions on the Lycopene Content in Tomatoes

M. Mayeaux, Z. Xu, J.M. King, and W. Prinyawiwatkul

ABSTRACT: Raw tomato contains a high level of lycopene, which has been reported to have many important health benefits. However, information on the changes of the lycopene content in tomato during cooking is limited. In this study, the lycopene content in raw and thermally processed (baked, microwaved, and fried) tomato slurries was investigated and analyzed using a high-performance liquid chromatography (HPLC) method. In the thermal stability study using a pure lycopene standard, 50% of lycopene was degraded at 100 °C after 60 min, 125 °C after 20 min, and 150 °C after less than 10 min. Only 64.1% and 51.5% lycopene was retained when the tomato slurry was baked at 177 °C and 218 °C for 15 min, respectively. At these temperatures, only 37.3% and 25.1% of lycopene was retained after baking for 45 min. In 1 min of the high power of microwave heating, 64.4% of lycopene still remained. However, more degradation of lycopene in the slurry was found in the frying study. Only 36.6% and 35.5% of lycopene was retained after frying at 145 and 165 °C for 1 min, respectively.

Keywords: baking, cooking, frying, lycopene stability, microwave, tomato

Introduction

Tomatoes have been traditionally credited as rich sources of carotenoids and vitamins, particularly beta-carotene, provitamin A, ascorbic acid, and vitamin C (Hanson and others 2004). In recent years, another important carotenoid in tomatoes, lycopene, has received considerable attention. Lycopene is responsible for the red color in tomatoes, watermelons, and pink grapefruits (Rao and Agarwai 2000). With a molecular formula of $C_{40}H_{56}$, lycopene has 11 conjugated double bonds and 2 nonconjugated double bonds, making it a highly unsaturated compound (Figure 1). Although, in tomatoes, beta-carotene and ascorbic acid are confirmed as being antioxidants of singlet oxygen (Hanson and others 2004), lycopene has been reported to quench singlet oxygen twice as good as beta-carotene and to be one of the most potent antioxidants of the carotenoids (Breeman and others 2002). The antioxidant capability of lycopene has led to promising results in decreasing the risk of some illnesses and cancers (Delgado-Vargas and Paredes-Lopez 2003). Several studies showed that lycopene is able to prevent the oxidation of low-density lipoprotein (LDL), which causes the atherogenic process and heart disease (Delgado-Vargas and Paredes-Lopez 2003).

In fresh tomatoes, the content of lycopene was reported to range from 2.5 to 200 mg/100 g of raw tomato (Takeoka and others 2001; Dewanto and others 2002; Seybold and others 2004). The level of lycopene is directly related to ripeness and increased pH (Thompson and others 2000). Thus, these factors may explain the wide variability of reported lycopene content in raw tomato. Also, changes of lycopene content in tomato during storage, semidrying, and paste or juice processing have been reported (Anguelova and Warthesen 2000; Takeoka and others 2001; Dewanto and others 2002; Hackett and others 2004; Seybold and others 2004; Goula and others 2006; Toor and Savage 2006). Although a decrease in lycopene content has been observed during these processes in some of the studies, an increase was found in other studies. This may be because the temperature (below 80 °C) used in those tomato processing methods increased free lycopene by disrupting cell walls or hydrolyzing lycopene derivatives rather than degrading the lycopene (Thompson and others 2000).

In this study, a pure lycopene standard was used for investigating the lycopene thermal stability in order to avoid any problems and discrepancies in the extraction and complicated status of lycopene content among raw and heat processed tomatoes. Therefore, the changes in the lycopene content during thermal processing were observed more accurately without involving the inconsistent factors found in the previous studies. Also, changes of lycopene in tomato were evaluated after being subjected to different cooking methods, including baking, microwaving, and frying. This provided valuable information on lycopene retention in tomatoes subjected to those intensive heat/cooking methods, which are generally used in daily tomato food preparation.

Materials and Methods

Chemicals

Hexane, methanol, and acetone were purchased from Fisher Scientific Inc. (Fair Lawn, N.J., U.S.A.). Lycopene was purchased from Sigma Chemical Co. (St. Louis, Mo., U.S.A.). Del Monte on-the-vine tomatoes (PLU nr 4664) were bought from a local market and chosen based on darkest red color, indicating ripeness.

Thermal stability study using the pure lycopene standard

Five hundred microliters of 1000 ppm lycopene in hexane were added into a 50-mL volumetric flask and diluted with hexane. Twenty-four 1 mL aliquots of the 10 ppm lycopene solution were taken and dried using a CentriVap Mobile system (Labconco, Kansas City, Mo., U.S.A.) at 60 °C. Each group of 8 of the 24 dried samples were placed in a sand bath at 100, 125, and 150 °C, respectively. Two samples were taken out from the bath at 10, 20, 30, and 60 min, respectively. After the samples were cooled, 1 mL methanol was added to all samples. The sample solutions were vortexed and transferred to

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high-performance liquid chromatography (HPLC) vials for determination of the lycopene concentration with an HPLC system. Results were based on percentage of retained lycopene as compared to the control without heating.

Tomato lycopene extraction

The lycopene in raw and cooked tomatoes was extracted using the method described by Periago and others (2004). A solvent mixture of acetone (1 mL), ethanol (1 mL), and hexane (1 mL) was added to a test tube with tomato sample (250 mg) and vortexed for 30 s. The extraction solution was kept at room temperature for 30 min and was vortexed every 10 min. After 30 min, 1 mL water was added to the solution. Then, the test tube was centrifuged at 1500 *g* for 10 min to separate the solution into distinct polar and nonpolar layers. The nonpolar supernatant layer containing lycopene was transferred to a clean tube. This supernatant solvent was evaporated using a CentriVap Mobile system at 60 °C. One milliliter of methanol was then added to the dried extract. The extract solution was vortexed and transferred to an HPLC vial. One hundred microliters of the solution were injected into an HPLC system for quantifying the concentration of lycopene.

Tomato cooking condition

To eliminate inconsistencies in lycopene content among the different tomatoes, tomatoes were homogenized to produce tomato slurry. The slurry was separated into aliquots of approximately 120 mL for each cooking condition. The cooking conditions are listed in Table 1.

For baking, 12 samples (25 g each) were weighed into baking cups and placed in a preheated oven immediately. The samples were baked at 177 °C (350 °F) and 218 °C (425 °F) because these temperatures are common in domestic cooking. Four samples were taken randomly from the oven at each time interval (15, 30, 35 min). After the samples were cooled, the remained weight of each baked sample was measured. Then, 250 mg of each sample, after it was mixed well, was taken for determination of lycopene content. Like the pure lycopene thermal stability study, results were based on percentage of retained lycopene compared to the control (raw tomato without cooking).

For microwaving, 20 samples (25 g each) were weighed into cups and cooked individually in a kitchen microwave with a rotating plate at a high power (approximately 1000 w) level. Four samples were cooked at each of the 5 time intervals (Table 1). The remaining weight of each sample was measured and mixed well after cooking. Then, 250 mg of each sample was taken for determination of lycopene content. The percentage of retained lycopene compared to the raw sample was used to express the degradation of lycopene.

For frying, each sample (25 g) was pan-fried individually with 2 Tbs (30 mL) pure vegetable oil (soybean oil) for each sample. The tomato slurry and oil were weighed together and mixed before frying. The weight of fried tomato slurry with oil was measured and mixed as well after frying. Then, 250 mg of the mixed fried tomato and oil sample was used in lycopene extraction. Three samples were cooked at each temperature/time combination (Table 1). The loss of lycopene was expressed by the percentage of retained lycopene compared to the raw sample.

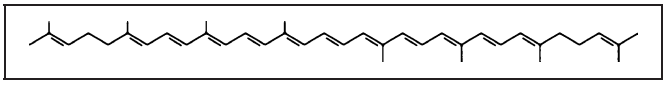

Figure 1 — Molecular structure of lycopene

Table 1 — Cooking conditions

Cooking method	Temperature (°C)	Time (min)
Baking	177	15; 30; 45 min
	218	15; 30; 45 min
Pan-frying	~145	60; 120 s
	~165	60; 120 s
Microwave cooking	High power (kitchen style, 1000 w)	10; 15; 30; 45; 60 s

HPLC analysis of lycopene

The HPLC system included Waters 510 pumps, a 715 Ultra WISP injector, a photo diode array detector (Milford, Mass., U.S.A.), and a 25 cm × 4.6 mm dia 5-μm C18 Discovery column (Supelco, Bellefonte, Pa., U.S.A.). The mobile phase was methanol:acetone (90:10) and the flow rate was 0.8 mL/min. The HPLC was controlled by Waters Millennium chromatography software and the lycopene peak was monitored at 470 nm. Lycopene concentration was calculated using a calibration curve prepared with the pure lycopene standard.

Statistical analysis

All data were analyzed using the SAS software v. 9.1.3 (SAS Inst. 2003). Results from the replicated trials for each thermal processing condition are presented as means with standard errors. Analysis of variance (ANOVA) was performed to determine differences in lycopene contents among different heating time/temperature conditions. The Tukey's standardized range test was used for posthoc comparisons to compare the means from 2 different treatment conditions.

Results and Discussion

Lycopene in raw tomato sample

The lycopene concentration in the raw tomato slurry of this study was 331 ± 3 mg/100 g, which is between the lycopene values of 311 and 670 mg/100 g of tomato reported by Dewanto and others (2002). However, it is higher than 80.27 and 120.67 mg/100 g of fresh tomato harvested in northern California in 1998 and 1999 (Takeoka and others 2001). The variety and growing environment could affect the biosynthesis and level of lycopene in tomato. Differences in the lycopene content were observed among cherry tomatoes and other cultivars that were grown in the field as compared to in the greenhouse (Kuti and others 2005). Lycopene biosynthesis inhibition in the greenhouse grown tomatoes might have been due to the occasional temperature buildup in the greenhouse (Kuti and others 2005). Along with variety and environmental factors, different extraction methods also cause differences in the lycopene level even in the same sample of tomato. In the study of Periago and others (2004), the best extraction yield was obtained by using a mixture of hexane, acetone, and methanol solvent, which was used in this study. Figure 2 is a representative chromatogram of lycopene in raw tomato slurry extracted using this solvent method. The profile of this chromatogram is similar to those reported in other studies, where C18 reversed phase column was used (Clinton and others 1996).

Stability of the pure lycopene standard during heating

The pure lycopene standard exhibited a decreasing stability as the temperature increased from 100 to 150 °C and as time increased from 0 to 60 min (Figure 3). After 10 min of heating, the pure lycopene was degraded with approximately 90%, 70%, and 30% of the original pure lycopene content remaining at temperatures of 100, 125, and 150 °C, respectively. The percentage of retained lycopene decreased to 53.5%, 20.9%, and 5.3% at 100, 125, and 150 °C, respectively, after 60 min of heating. The results indicate that lycopene is

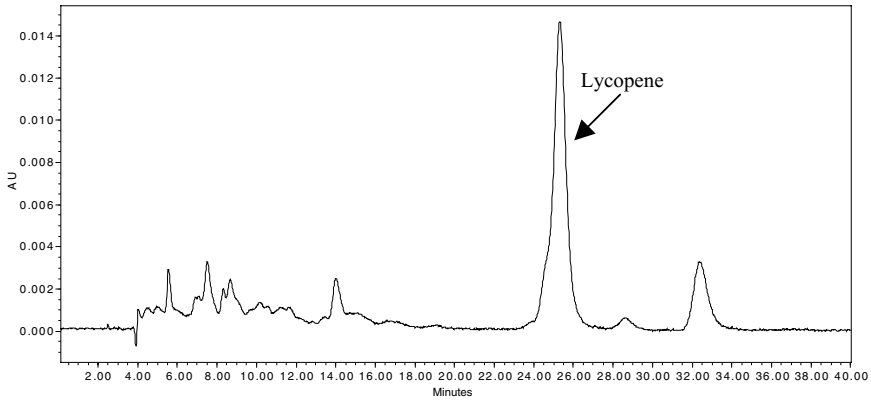

Figure 2—A representative chromatogram of lycopene in raw tomato sample used in this study. HPLC conditions: column, 25 cm × 4.6 mm diameter 5-μm C18; mobile phase, methanol: acetone 90:10; flow rate, 0.8 mL/min; detector wavelength, 470 nm.

not stable during long heating times and rapidly decomposed at a heating temperature of 150 °C and above. The proposed pathway of lycopene degradation consists of 2 stages: isomerization and autoxidation due to the unsaturated double bonds (Boskovic 1979). The degradation of lycopene occured at a temperature as low as 25 °C through oxidation without isomerization (Hackett and others 2004). The isomerization of lycopene increased at a temperature above 75 °C (Hackett and others 2004; Mayer-Miebach and others 2005). However, other studies found that lycopene increased during the thermal processing of tomato products (Dewanto and others 2002; Seybold and others 2004; Toor and Savage 2006). Factors induced in the food processing, such as enzymes in raw tomato, heating temperature, and additives, could affect the stabilities of tomato lycopene. Also, the real thermal stability of lycopene could not be clearly revealed in a study using raw tomato or a product that potentially contains heat-induced lycopene precursors, which are lycopene derivatives and broken down to produce free lycopene during heating. In this study, a high-purity lycopene was used to observe the stability during heating. This approach eliminated the interferences such as precursors and enzymes. The results could be useful in obtaining a more comprehensive understanding of the thermal stability of lycopene.

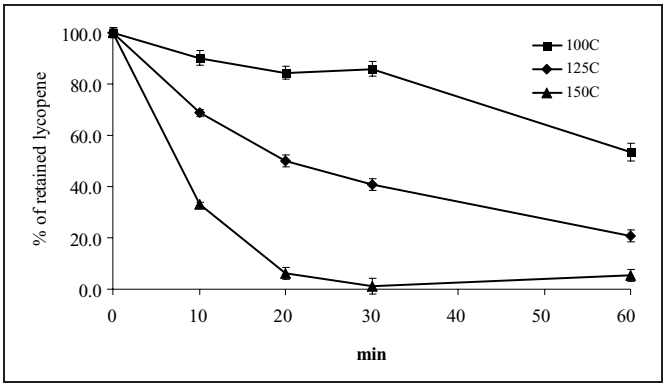

Figure 3—Lycopene retention (%) at different heating temperatures over time

Changes of lycopene content in tomato slurry after cooking by different methods

The retained lycopene percentages in tomato slurry after microwaving, frying, and baking are shown in Figure 4. The microwave cooking used in this study resulted in the relatively higher percentage of retained lycopene because the tomato slurry reached its boiling point after only 60 s of microwave cooking. The temperature of the tomato slurry was not as high as either baking or frying. Approximately 35% of lycopene in the slurry was lost after heating at the highest power of a 1000 w kitchen microwave for 60 s. Thus, the microwave cooking caused the least amount of lycopene degradation in the short heating time. For baking, the percentage of retained lycopene for the samples baked at 177 °C (350 °F) for 15, 30, and 45 min were 64.1%, 45.6%, and 37.3%, respectively (Figure 4). Compared with 51.5%, 41.3%, and 25.1% for the samples baked at 218 °C (425 °F), the moisture content in tomato could result in the significant difference of lycopene stability between heating the pure lycopene standard and cooking the tomato samples. Moisture could help to slow down the heat transfer to the tomato slurry and hydrolyze possible lycopene derivatives to produce more free lycopene. Although the baking temperature was higher than that used in the pure lycopene study, the retained lycopene in the tomato slurry during baking for 60 min was higher than that in the pure lycopene standard study. Decreases of about 35% and 50% of lycopene were reported in tomato juice after being sterilized at 121 °C for 2 min or pasteurized at 80 °C for 20 min and in tomato soup after 50 min cooking, respectively (Seybold and others 2004). Less than 10% of lycopene was lost during production of a semidried tomato at 42 °C (Toor and Savage 2006). However, at 88 °C cooking temperature, increases of *trans* lycopene were found during 30 min heating (Dewanto and others 2002). This suggested that mild thermal processing could simultaneously increase lycopene concentration in tomato products by increasing the free and bioaceesible form while degrading lycopene through oxidation. The heating temperature and time may play an important role in lycopene concentration in tomato. The lycopene in tomato slurry was very severely degraded during frying as compared to the samples that were microwaved and baked. Approximately 70% and 75% of lycopene was lost during frying for 2 min at temperatures of 145 and 165 °C, respectively (Figure 4). With frying, the tomato temperature spiked immediately, causing a drastic loss in moisture and lycopene in the initial minutes of exposure to the frying temperature. The high frying temperatures could cause the oil to produce hydroperoxide free radicals and accelerate the degradation of lycopene as well.

Conclusion

Like in the pure lycopene model, the percentage of retained lycopene in tomato slurry decreased with time and temperature. This study suggested that lycopene is not stable when exposed to cooking temperatures above 100 °C. While microwaving and baking are less severe treatments that can degrade lycopene, frying could cause serious loss of lycopene in tomato.

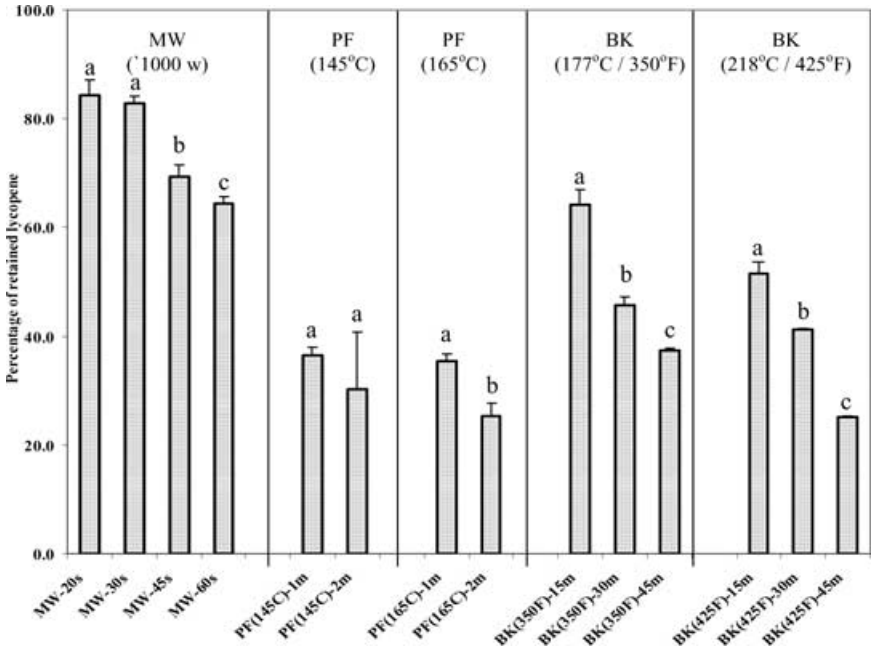

Figure 4—Percentage of retained lycopene for microwaved, pan-fried, and baked tomato samples (MW–microwave cooking; PF–pan-frying; BK–baking). *Significant difference ($P < 0.05$) between 2 columns in the same cooking condition is expressed by different letters.

References

Anguelova T, Warthesen J. 2000. Lycopene stability in tomato powders. J Food Sci 65:67–70.

Boskovic MA. 1979. Fate of lycopene in dehydrated tomato products: carotenoid isomerization in food system. J Food Sci 44:84–6.

Breeman R, Xu X, Viana M, Chen L, Stacewiez-Sapuntzakis M, Duncan C, Bowen P, Sharifi R. 2002. Liquid chromatography-mass spectrometry of cis- and all-trans-lycopene in human serum and prostate tissue after dietary supplementation with tomato sauce. J Agri Food Chem 50:2214–19.

Clinton SK, Emenhiser C, Schwartz SJ, Bostwick DG, Williams AW, Moore BJ, Erdman JW. 1996. *Cis-trans* lycopene isomers, carotenoids, and retinol in the human prostate. Cancer Epidem Biomar 5:823–33.

Delgado-Vargas F, Paredes-Lopez O. 2003. Chemicals and colorents as notraceuticals. In : Delgado-Vargas F, Paredes-Lopez, O, editors. Natural colorants for food and nutraceutical uses. Boca Raton, Fla.: CRC Press. p 257–298.

Dewanto V, Wu X, Adom KK, Liu RH. 2002. Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. J Agri Food Chem 50:3010–4.

Goula AM, Nikas VA, Chatzitakis PC, Adamopoulos KG. 2006. Prediction of lycopene degradation during a drying process of tomato pulp. J Food Eng 74:27–46.

Hackett MM, Lee JH, Francis D, Schwartz SJ. 2004. Thermal stability and isomerization of lycopene in tomato oleoresins from different varieties. J Food Sci 69:536–41.

Hanson PM, Ledesma D, Tsou SCS, Lee TC, Yang R, Wu J, Chen J. 2004. Variation of antioxidant activity and antioxidants in tomato. J Am Soc Hort Sci 129:704–11.

Kuti JO, Hima KB. 2005. Effects of genotype and cultivation environment on lycopene content in red-ripe tomatoes. J Sci Food Agri 85:2021–6.

Mayer-Meibach E, Schuchmann HP, Regier M, Behsnilian D. 2005. Thermal processing of carrots: lycopene stability and isomerization with regard to antioxidant potential. Food Res Int 38:1103–8.

Periago MJ, Rincon F, Aguera MD, Ros G. 2004. Mixture approach for optimizing lycopene extraction from tomato and tomato products. J Agri Food Chem 52:5796–802.

Rao AV, Agarwai S. 2000. Role of antioxidant lycopene in cancer and heart disease. J Am Coll Nutri 19:563–9.

SAS Inst. 2003. SAS/STAT user's guide, ver. 1.1.3. Cary, N.C.: SAS Institute Inc.

Seybold C, Frohlich K, Bitsch R, Otto K, Bohm V. 2004. Changes in contents of carotenoids and vitamin E during tomato processing. J Agri Food Chem 52:7005–10.

Takeoka GR, Dao L, Flessa S, Gillespie DM, Jewell WT, Huebner B, Bertow D, Ebeler SE. 2001. Processing effects on lycopene content and antioxidant activity of tomatoes. J Agri and Food Chem 49:3713–7.

Thompson KA, Marshall MR, Sims CA, Wei CI, Sargent SA, Scott JW. 2000. Cultivar, maturity and heat treatment on lycopene content in tomatoes. Food Chem 65: 791–5.

Toor RK, Savage GP. 2006. Effect of semi-drying on the antioxidant components of tomatoes. Food Chem 94:90–7.