Evaluation of processing qualities of tomato juice induced by thermal and pressure processing

Kuo-Chiang Hsu*

Department of Health Diet and Restaurant Management, Chung Shan Medical University, 110, Sec. 1, Chien-Kuo N. Rd., Taichung 402, Taiwan, ROC

Received 22 October 2006; received in revised form 22 March 2007; accepted 27 March 2007

Abstract

Effects of processing conditions including hot-break processing (92 °C for 2 min), cold-break processing (60 °C for 2 min) and hydrostatic pressure treatments (100–500 MPa) at different temperatures (4, 25 and 50 °C) for 10 min on quality aspects of tomato juice were investigated. Both hot- and cold-break processing induced significant changes in color, viscosity and radical-scavenging capacity of tomato juice compared with control (fresh tomato juice); moreover, hot-break processing induced a specific range of reduction of pectin methylesterase (PME) and polygalacturonase (PG) activities. Pressure treatments at and below 200 MPa at 4 and 25 °C maintained the color, extractable total carotenoids and lycopene, and radical-scavenging capacity; further, those at 500 MPa at 4 and 25 °C improved all the quality attributes the most except inactivation of PME in this study. The residual activity of PME showed the lowest after treating by 200 MPa at 25 °C; however, the PME activity was enhanced by treatments at 300–500 MPa and various temperatures. The residual activity of PG decreased gradually to 72% with pressure elevated from 100 to 400 MPa at 4 and 25 °C, further, that declined quickly to 10% after 500 MPa treatments. This research clearly shows that it is possible to selectively produce good tomato juice products by high pressure processing at ambient temperature.

Keywords: Tomato juice; Hydrostatic pressure; Hot-break processing; Cold-break processing; Lycopene; Radical-scavenging capacity

1. Introduction

Besides microbial safety, important quality aspects of tomato products are color, flavor, and consistency (Hayes, Smith, & Morris, 1998). In tomato products, an important reaction during thermal processing is the degradation of the red pigment lycopene, originally in the trans form, due to isomerization to the cis form resulting in color changes (Rodrigo, van Loey, & Hendrickx, 2007). Moreover, in tomato juice products stabilized by thermal processing, the changes of color and flavor can also be caused by non-enzymatic browning (Porretta, 1991; Servili, Selvaggini, Taticchi, Begliomini, & Montedoro, 2000).

Consistency of tomato products refers to their viscosity and the ability of their solid portion to remain in suspension throughout the shelf life of the product. The consistency of tomato products is strongly affected by the composition of the pectins. Controlling the breakdown or retention of the pectins, and the enzymes that lead to changes in the pectins, is thus of great importance during processing (Hayes et al., 1998). Two enzymes, pectin methylesterase (PME) and polygalacturonase (PG), are involved in the breakdown of pectins. The action of PME makes the pectin susceptible to further degradation by PG because this enzyme acts only on segments of the pectin chain that have been demethylated by PME. The degradation of the pectin chains reduces the viscosity of the juice. Two different process are commonly used in the production of tomato products. In the hot-break process, tomatoes are rapidly heated to 90–95 °C immediately after homogenization. This process is believed to inactivate enzymes rapidly, particularly those involved in pectin degradation, and gives a product with high viscosity. In the cold-break process, the homogenized tomatoes are heated only to around 60 °C. This is believed to have benefits in the production of products such as juice. The lower temperature reduces the amount of thermal abuse of...
the product, giving a greater retention of color and flavor components and reducing production of undesirable compounds. The lower temperature also does not entirely inactivate the enzymes PME and PG and allows these enzymes to break down of some of the pectins reducing the viscosity of the juice (Luh & Daouf, 1971).

The consumption of tomato products has been associated with a lower risk of developing digestive tract and prostate cancers (Giovannucci, Rimm, Liu, Stampfer, & Willett, 2002) due to the ability of lycopene and other antioxidant components to prevent cell damage through synergistic interactions (Friedman, 2002; George, Kaur, Khurdiya, & Kapoor, 2004).

Effects of thermal processing on the processing qualities of tomato juices had been widely investigated (Sieso & Crouzet, 1977; Sánchez-Moreno, Plaza, de Ancos, & Cano, 2006a). The volatile components and vitamin C of canned tomato juice can be reduced by treatments at 100 °C for 10 min (Sieso & Crouzet, 1977; Youssef & Rahman, 1982). The color of tomato juice degraded more rapidly with increasing temperature, therefore, one of the advantages of cold break over hot break is that the final product had more natural color (Goodman, Fawcett, & Barringer, 2002; Sánchez-Moreno et al., 2006a). On the other hand, thermal treatments would increase the overall antioxidant potential of the tomato juice coincide with the positive effect of the temperature on the extractability of lycopene (Anese, Manzoeco, Nicoli, & Leric, 1999; Anese, Falcone, Fogliano, Nicoli, & Massini, 2002; Sánchez-Moreno et al., 2006a). Besides, lycopene in tomato is relative resistant to thermal degradation, whereas other antioxidants (ascorbic acid, tocopherol and β-carotene) degrade more rapidly by thermal processing (Abushita, Daoed, & Biac, 2000). At temperatures higher than 78 °C for 40 s and 90 °C for 5 min, respectively, PME and PG in tomato juices could be completely inactivated (De Sio, Dipollina, Villari, Loidice, Laratta, & Castaldo, 1995; Fachin et al., 2003).

Thermal processing is conventionally used to inactivate microorganisms and enzymes and extend the shelf life of juice products. However, thermal processing can adversely affect the sensory and nutritive qualities of tomato juices (Youssef & Rahman, 1982; Goodman et al., 2002). The consumers demand safe, fresh and minimally processed foods, therefore, a nonthermal food processing such as hydrostatic pressure has developed (Popper & Knorr, 1990; Knorr, 1993). Hydrostatic pressure processing is a technology that applies a pressure between 200 and 700 MPa to inactivate vegetative microorganisms and preserve food (Hoover, Metrick, Papineau, Farkas, & Knorr, 1989), and quality-related enzymes (Weemaes, Ludikhyuze, Van de Broeck, & Hendrickx, 1998). Due to the only non-covalent bonds being affected by pressure, high pressure processing can be an alternative for heat treatment in the context of food preservation (Cheftel, 1992). Some researchers have demonstrated that high pressure processing improved viscosity and color properties in comparison with their conventional heat-processed counterparts (Porretta, Birzi, Ghizzoni, & Vicini, 1995). PG in tomato-based products could be totally inactivated at some pressure/temperature combinations: 550 MPa/20 °C (Fachin et al., 2003); 500 MPa/60 °C (Crelier, Robert, & Juillerat, 1999) and 800 MPa/25 °C (Shook, Shellhammer, & Schwartz, 2001). Tomato PME, a heat-labile enzyme at ambient pressure, was dramatically stabilized against thermal denaturation at pressures above atmosphere and up to 500–600 MPa, and was completely inactivated at 800 MPa/70 °C over 20 min (Crelier, Robert, Claude, & Juillerat, 2001).

Surprisingly, few researchers have reported that the effect of high pressure treatments at various temperatures, especially refrigerated temperature, on the processing quality of tomato juice. Therefore, the main objective of this research was to investigate the effects of high pressure treatments at various temperatures (100–500 MPa/4, 25, 50 °C/10 min) on the processing qualities of tomato juice, such as carotenoids, radical-scavenging capacity, PME and PG activities, in comparison with those of traditional thermal processing (hot and cold break). And this study was also tried to prove pressure processing as an alternative for thermal processing of tomato juice.

2. Materials and methods

2.1. Tomatoes and juice preparation

Fresh harvested red daydream tomatoes were purchased from Yenshui Farmer’s Association in Tainan County, Taiwan. Daydream tomatoes were stored at 7 °C before treatments within 7 days. Washed tomatoes (200 g), equilibrated at room temperature for 1 h, were homogenized twice by a warring-blender with the high speed for 10 s and sieving (0.8 mm holes) to remove pieces of skin and any seeds. The pH value of the raw juice was in the range of 3.8–4.2 and adjusted to 4.5 by 10 mol/L NaOH. The tomato juice was obtained as the control in this study and used for the following treatments in less than 3 min for preventing apparent degradation of pectins by PME and PG.

2.2. Thermal treatment (hot break and cold break)

Tomato juice (150 g) was poured into double polyethylene bags (250 × 360 mm, thickness: 50 μm, Medisch Labo Service, Menen, Belgium) and vacuum sealed followed by hot break (92 °C; 2 min) or cold break (60 °C; 2 min) in a water bath. The treated juice was immediately cooled to about 15 °C in ice water for 2 min, wrapped with aluminum foil and equilibrated at room temperature for 10 min. The tomato juice was then proceeded to the quality measurements in 10 min.

2.3. Combined pressure–temperature treatments

Tomato juice was filled into polyethylene pouches (10 cm × 13 cm, capacity 200 mL) which were vacuum
sealed and then enclosed in the pressure vessels already equilibrated at 4, 25 or 50 °C. The pressure medium is deionized water. The samples were assayed at pressures from 100 to 300 MPa for 10 min. Pressure was built up by 200 MPa/min and drop by 400 MPa/min. Pressure treatment time did not include pressure build up and releasing time. After treatments, the tomato juice was immediately cooled to about 15 °C in ice water for 2 min, wrapped with aluminum foil and equilibrated at room temperature for 10 min. The tomato juice was then proceeded to the quality measurements in 10 min.

2.4. High pressure equipment

A high pressure apparatus (CIP UNIT, Mitsubishi Heavy Industries Ltd., Japan) with an oil-pressure generator and a compressing vessel, in which the internal portion (diameter: 50 mm; height: 120 mm) was a flat-bottomed cylindrical shape, was employed. The vessel temperatures during pressure treatments were controlled by a circulator.

2.5. Color

Hunter L, a, and b of tomato juice were measured by a HunterLab colorimeter (Color Meter ZE-2000, Nippon Denshoku Co., Japan). The red–yellow ratio (a/b) was reported to indicate the redness of tomato juice (Min & Zhang, 2003).


A 8 g juice sample was mixed with 40 mL of ethanol–hexane (4:3, v/v) and 0.2 g magnesium carbonate. The solution was shaken in a shaker at 140 rev/min for 30 min, which the upper layer was collected in a flask. The lower layer was further extracted with 32 mL ethanol–hexane (4:3, v/v) and shaken for 30 min. Again, the upper layer was collected in the same flask. The lower layer was repeatedly extracted with 15 mL hexane and shaken for 20 min, followed by addition of 5 mL hexane and the solution was homogenized by a polytron (PT-3000, KINEMATICA AG, Switzerland) at 12,000 rpm for 20 min, followed by addition of 5 mL hexane and the solution was filtered through Whatman no.1, centrifuged at 18,200 g for 10 min and the supernatant was removed and PG was extracted from the pellets with 1.2 mol/L NaCl (1:1) for 1 h. The mixture was centrifuged at 18,200 g for 10 min and the supernatant was assayed for PG activity. All activities of tomato juice samples are reported as the percentage of the activities of the control.

2.7. Viscosity

The viscosity of tomato juice was studied using a Brookfield viscometer, springle #4 at 10 rpm, 25 °C and only the 10th round readings were recorded (mPa s) (Oke, Ahn, Schofield, & Paliyath, 2005).

2.8. PME activity (Anthon, Sekine, Watanabe, & Barrett, 2002)

A 30 mL aliquot of a solution containing 0.2 mol/L NaCl and 1.0% pectin (P9135, from citrus, Sigma, St. Louis, MO) was equilibrated and adjusted to pH 7.0. Following the addition of 1.0 mL of the tomato juice, the pH was readjusted to 7.0 and maintained at this value for 10 min by use of a titration stand consisting of Metrohm 691 pH meter, 614 Impulsomat, and 665 Dosimat (Metrohm AG, CH-9100 Herisau, Switzerland). The volume $V_{NaOH}$ of base (0.005 N sodium hydroxide) was then monitored as a function of time on a Philips PM 8262 X/t recorder. All samples were measured in triplicate at 21 °C.

The rate was calculated as μmol of NaOH consumption by the control being boiled for 20 min was subtracted as a blank. All activities of tomato juice samples are reported as the percentage of the activities of the control.

2.9. PG activity (Anthon et al., 2002; Fachin et al., 2003; Pressey, 1986)

Five mL of tomato juice was centrifuged (Hitachi Centrifuge 05P-21, Katsuda, Japan) at 7500 g for 10 min, the supernatant was replaced by cold distilled water (1:1) adjusted the pH to 3.0 with 0.1 mol/L HCl and mixed for 30 min. After centrifuging at 9000 g for 20 min, the supernatant was removed and PG was extracted from the pellets with 1.2 mol/L NaCl (1:1) for 1 h. The mixture was centrifuged at 18,200 g for 10 min and the supernatant was assayed for PG activity. All steps were performed at 4 °C.

The PG activity assay was based on the release of reducing groups produced by PG and measured using a spectrophotometric method. 0.1 mL of the extracted enzyme solution was incubated in a test tube with 0.3 mL of 0.2 g/100 g polygalacturonic acid at 35 °C for 10 min. To terminate the reaction, 2 mL of 0.1 mol/L borate buffer (pH 9.0) and 0.4 mL of 1 g/100 g cyanocacetamide were added to the reaction mixture and boiled in a water bath for 10 min. For preventing the moisture loses of the reaction mixture during boiling, the test tube was covered with a cap. After cooling to room temperature, the absorbance was measured at 276 nm (Hitachi U-2000,
Katsuda, Japan). Blank samples were determined in the same way with the control being boiled for 20 min. Each sample was measured in duplicate. All activities of tomato juice samples are reported as the percentage of the activities of the control.

2.10. Scavenging effect on DPPH radical (Sánchez-Moreno, Plaza, de Ancos, & Cano, 2003a; Sánchez-Moreno et al., 2006a)

Two fractions (hydrophilic and hydrophobic fractions) were prepared from tomato juices and used in the antioxidant assay. Each tomato juice sample (30 g) were extracted with 10 mL of sodium phosphate buffer (0.1 mol/L, pH 3.0) and centrifuged at 12,000 g for 20 min at 4 °C. The pellet was homogenized with 20 mL of sodium phosphate buffer (0.1 mol/L, pH 7.4) and centrifuged at 10,000 g for 15 min at 4 °C. Supernatants were combined to yield the hydrophilic fraction. The pellet was then extracted with 20 mL of tetrahydrofuran (THF; Sigma Chemical Co., St. Louis, MO, USA) three times and centrifuged at 10,000 g for 10 min at 4 °C. Supernatants were combined to yield the hydrophobic fraction. The solvent was evaporated to dryness in a vacuum rotary evaporator at 40 °C and the organic residue was dissolved in 3 mL of a Tween 20 solution (10 g/100 g THF). An aliquot of sample fraction (0.1 mL) with appropriate dilution was added to 3.9 mL of DPPH (3.0 × 10⁻⁶ g/L, Sigma Chemical Co., St. Louis, MO, USA) in methanol. The decrease in absorbance was determined by a spectrophotometer (Hitachi U-2000, MO, USA) in methanol. The decrease in absorbance was calculated with 20 mL of DPPH (0.1 mL) with appropriate dilution was added to 3.9 mL of DPPH (3.0 × 10⁻⁶ g/L, Sigma Chemical Co., St. Louis, MO, USA) in methanol. The decrease in absorbance was determined by a spectrophotometer (Hitachi U-2000, Japan) at 515 nm at 0.5 min intervals until the reaction reached a plateau (time at the steady state). A calibration curve at 515 nm was made with DPPH to calculate the DPPH concentration in the reaction medium.

The parameters EC₅₀, which reflects 50% depletion of the initial DPPH and the time needed to reach the steady state at EC₅₀ concentration (T_EC₅₀) were calculated. The antiradical efficiency (AE = 1/EC₅₀T_EC₅₀), a parameter that combines both factors, was also calculated (Sánchez-Moreno, Larrauri, & Saura-Calixto, 1998).

2.11. Statistical analysis

The Statistical Analysis System (SAS Institute Inc., Cary, NC, USA) was adopted for performed data analysis and statistical computations for analysis of variance (ANOVA) and Duncan’s test. Significant differences were defined at p ≤ 0.05. All treatments were verified by their least significant difference. Experiments were conducted in triplicate.

3. Results and discussion

3.1. Color

Effects of thermal and pressure processing on the red–yellow ratio, indicating the redness of tomato juices, are shown in Fig. 1. An a/b ratio of 1.90 or greater represents a first quality product in terms of color and an a/b ratio of less than 1.80 means that the tomato products may be unacceptable for inclusion in products where a bright red color is desired (Hayes et al., 1998). The a/b value of the control was 3.62 and appreciated more than that of hot-break tomato juice of 3.30 (p ≤ 0.05) and cold-break tomato juice of 3.54. The result in a low a/b value represented an orange to brown color due to the breakdown of lycopene and formation of Maillard reaction products by the intensive heat treatment (Shi & Le Maguer, 2000; Krebbers, Matser, Hoogerwerf, Moezelaar, Moormann, & van den Berg, 2003). The a/b values of the pressure-treated samples were significantly greater than that of control or thermally treated samples. And a/b values of tomato juice increased up to 3.84 with pressure levels elevated to 500 MPa. Results suggest that an increase in the red color (a value; data not shown) of high pressure treated tomato juice compared to thermal treatments, attributed to the better homogenization and brightening of the red color (Porretta et al., 1995; Krebbers et al., 2003). However, contradictory results can be found in literature about the effect of high pressure on other fruits and vegetables. Combined high pressure and thermal treatments at 300–700 MPa/65 °C for 60 min did not significantly change the L* a*/b* parameter of tomato puree, however, 600–700 MPa significantly increased the same parameter of strawberry juice at pH 5.0 for 8.8% (Rodrigo et al., 2007). A high retention of red color was observed when high pressure treating strawberries (Matser & Bartels, 1999). Also, high pressure has been found to induce discoloration in mushrooms and onions because of the activity of the enzyme polyphenoloxidase, responsible for browning (Butz, Koller, & Tauscher, 1994). Those discrepancies might be due to the different color contributors, color degradations and various processing conditions.
conditions, including pH, time and temperature (Rodrigo et al., 2007).

3.2. Carotenoids and lycopene

The total carotenoids and lycopene contents of control are 212.8 and 145.6 mg/g, respectively (data not shown), which are higher than those of tomato (Tzu-Tai Lan 93) juices by about 20% probably due to different cultivars (Lin & Chen, 2003). After the cold and hot break, both total carotenoids and lycopene contents of tomato juices slightly but insignificantly decreased about 1% ($p < 0.05$) (Fig. 2). However, the positive effect of temperature on the extractability of lycopene is described in the literature, this effect being time-dependent (Porrini, Riso, & Testolin, 1998). Increases in lycopene concentration in tomato puree have been shown at 90°C/110 min and 110°C/1.1 min but not at 120°C/0.1 min (Anese, Falcone, Fogliano, Nicoli, & Massini, 2002). The results showed that cold and hot break applied to tomato juice in this study did not induce lycopene extractability or degradation probably owing to insufficient temperature and time. Further, the color degradation occurring by both thermal treatments in this study was caused by nonenzymatic reactions (Fig. 1).

After high pressure processing beyond 300 MPa at 4 and 25°C, both total carotenoids and lycopene contents significantly increased up to 62% and 56%, respectively, as compared with control (Fig. 2). It has been reported that high pressure treatment (500 MPa/20°C/2 min) increased the lycopene content of tomato puree compared with the raw puree (Krebbers et al., 2003). In addition, some researchers have shown increases in extractable carotenoids and lycopene as a result of high pressure treatment (400 MPa/25°C/15 min) of tomato puree (Sánchez-Moreno, Plaza, de Ancos, & Cano, 2006b). The result could explain the increased redness of tomato juice after high pressure treatments (Fig. 1). However, high pressure treatments below 200 MPa at 4 and 25°C might only slightly modify the protein structure which is bound with carotenoids but could not induce the extraction of the pigments. Total carotenoids and lycopene contents of the tomato juices by high pressure treatments at 50°C were much lower than those at either 4 or 25°C, probably owing to the preventing effect on protein thermal denaturation at denaturing temperatures (Heremans & Smeller, 1998). It has been reported that high pressure treatment can affect the membranes in vegetable cells (Shi & Le Maguer, 2000). In addition, carotenoids are tightly bound to macromolecules, in particular to protein and membrane lipids, and high pressure processing is known to affect macromolecular structures such as proteins and polymer carbohydrates (Gärtner, Stahl, & Sies, 1997).

3.3. Viscosity

The viscosity of fresh tomato juice (control) was 1875 mPa s and shown in Fig. 3. Hot-break juice had a significantly higher viscosity (1986 mPa s) than control and cold-break juice (1547 mPa s) ($p < 0.05$). Some researchers reported that when using hot-break method, the temperatures are high enough forpectolytic enzyme inactivation, and this leads to a concentrate of greater viscosity (Fito, Clemente, & Sanz, 1983; Goodman et al., 2002). In addition, break temperature influences the viscosity of tomato products by changing pectin retention (Xu, Shoemaker, & Luh, 1986), but the effect was eliminated due to the insignificant contribution of pectins to the viscosity of tomato juice (Foda & McCollum, 1970). Therefore, this study mainly showed that viscosity differences are caused by enzyme activity.

Viscosity of tomato juice increased linearly with pressure level elevated from 100 to 500 MPa at various temperatures (4, 25 and 50°C), however, the viscosity loss occurred with the pressures at 100 and 200 MPa in comparison with control (Fig. 3). Three hundred MPa treatments at various temperatures resulted in retention of the viscosity. This may partly be caused by heat- or enzymatic-degradation of pectins (Thakur, Singh, & Nelson, 1996). Four hundred and 500-MPa treatments could improve (increase) the viscosity up to 20%. The results were probably due to PG inactivation, compacting effects, or protein–tissue coagula-
tion (Porretta et al., 1995; Krebbers et al., 2003). Some researchers showed contradictory results that the highest loss in consistency of the tomato homogenate after combined pressure–temperature treatment was found at 300 MPa at all temperatures tested (30–70 °C) for 15 min compared with those at the other pressure levels from 100 to 500 MPa (Verlent, Hendrickx, Rovere, Moldenaers, & van Loey, 2006). They explained that purified tomato PME was very active in presence of tomato PG at pressure up to 300 MPa. PME creates a good substrate for PG, which also has a sufficient high activity at 300 MPa. However, they did not determine the activity of PME in tomato homogenate which was treated by pressure. Moreover, high pressure sterilization (700 MPa/80 or 90 °C) of tomato puree brought about a considerable reduction in viscosity may be due to the relative long preheating time applied to reach the starting temperature (80 or 90 °C) for pressurization (Krebbers et al., 2003). The results in the loss of viscosity of tomato juice also showed that the treating pressure levels behind 200 MPa could not inactivate both PME and PG.

3.4. PME and PG activity

Effects of the thermal and high pressure treatments on the PME and PG activities in tomato juices were shown in Fig. 4. After the cold-break processing, PME and PG activities decreased 30% and 12%, respectively, meanwhile, the residual activities of the both enzymes were lower than 2%. Thermal inactivation of the both enzymes in tomato juices were investigated in some literature. PG in tomato juice (at natural pH value) was completely inactivated by thermal treatment at 93 °C for 3 min (Fachin et al., 2003), moreover, at the temperature ranged from 55–60 °C, the residual PG activity was 60–80% due to the presence of heat stable PG1. PME in tomato juice (pH 4.2) was almost completely inactivated by thermal treatment at 88 °C for 20 s, and the residual activity was about 30% after a treatment at 73 °C for 80 s (De Sio et al., 1995).

After the high pressure treatments at 100 MPa and all temperatures, the residual activities of PME unchanged or insignificantly reduced compared with control (Fig. 4). The initial activity was reduced to 27.8% using the treatment of 200 MPa at 25 °C, and this combination was the most efficient in terms of PME inactivation. The higher efficiency of low-pressure/mild-temperature treatments on tomato puree PME was also reported (Hernández & Cano, 1998). Several studies have pointed out that polymeric proteins, stabilized by non-covalent bonds, are dissociated at low pressures (Balny & Masson, 1993). However, an activation effects were observed in the cases of higher pressure (beyond 300 MPa) treatments at all temperatures in this study, could be attributed to reversible configuration and/or conformation changes of the enzyme and/or substrate molecules (Ogawa, Fukuhisa, Kubo, & Fukumoto, 1990). Maximal PME activity was observed at 300 MPa and 50 °C and almost 1.7 times as control.

PG activity was strongly reduced up to 90% by the high pressure treatments beyond 400 MPa at ambient and low temperatures (25 and 4 °C). However, pressure from 100 to
300 MPa had slight or insignificant effects on inactivation of PG up to 14%, demonstrating the pressure resistance of PG (Krebbers et al., 2003). At 50 °C, PG was more resistant to high pressure treatments probably due to reversible configuration of the enzyme, and the result was confirmed in literature (Fachin et al., 2003). The increased activity of PME and the inactivation of PG may to some extent be an explanation for the observed increase in viscosity compared to control and thermal treating juices. However, this cannot explain the tendency of increased viscosity at higher pressures. The similar results were reported in literature (Krebbers et al., 2003).

### 3.5. Scavenging effect on DPPH radical

The scavenging effect on DPPH radical measurement can estimate the capacity of the most reactive compounds against a reference radical (Anese et al., 2002), therefore, we adopted this method instead of other measurements of antioxidant activity, such as redox potential. In tomato products, vitamin C and polyphenols (flavonoids and hydroxyxycinnamic acids) are reported to be the major antioxidant hydrophilic components, and vitamin E and carotenoids mainly constitute the hydrophobic fraction (Takeoka et al., 2001; Martinez-Valverde, Periago, Provan, ...
The radical-scavenging capacities of hydrophilic and hydrophobic fractions of tomato juices by different treatments were, respectively, evaluated (Fig. 5a and b). Until now, no data have been available about the radical-scavenging capacity of tomato juices by high pressure/temperature combinations.

3.6. Hydrophilic fraction

The EC\textsubscript{50} and T\textsubscript{EC50} values of the hydrophilic fraction of control were 68.2 g/g DPPH and 20.8 min, respectively (Fig. 5a). After hot- and cold-break treatments, both EC\textsubscript{50} and T\textsubscript{EC50} values significantly increased (p < 0.05) due to the depletion in vitamin C (Dewanto, Wu, Adom, & Liu, 2002; Sánchez-Moreno et al., 2006b). Thermal processing at 88°C for 2, 15 and 30 min decreased the vitamin C content in tomatoes, however, there was no loss or gain in content of both total phenolics and flavonoids (Dewanto et al., 2002). The results showed that the radical-scavenging capacity of tomato juice decreased by thermal treatments at 60 and 92°C for 2 min.

Pressure processing beyond 300 MPa at 4 and 25°C maintained the radical-scavenging capacity of tomato juice compared with control due to the values of EC\textsubscript{50}, T\textsubscript{EC50} and AE with no significant differences (p > 0.05). As the pressures were behind 200 MPa at 4°C only, the radical-scavenging capacity of tomato juices were unchanged (p < 0.05). Pressure processing (100–500 MPa) at 50°C significantly decreased the AE values of tomato juices, which indicated that the loss of radical-scavenging capacity was mainly due to the high temperature treatment. Previous studies in orange juices showed that the depletion of vitamin C after combined treatment of high pressure/temperature was dependent mainly on temperature intensity, showing losses after 400 MPa/40°C/1 min, but not after 350 MPa/30°C/2.5 min (Sánchez-Moreno et al., 2003b). The results in this study showed that pressures beyond 300 MPa at 4 and 25°C had positively protective effect on the radical-scavenging capacity of tomato juices, and those are in agreement with Fernandez Garcia Butz, and Tauscher (2001), who reported that the water-soluble antioxidative capacity [2,2′-azino-bis-(ethylbenzothiazoline-6-sulfonic acid) diammonium salt; ABTS\textsuperscript{+} assay] of tomato puree processed by high pressure treatments (500 and 800 MPa/20°C/5 min) was not, or only insignificantly, reduced compared to that of untreated puree. On the contrary, probably due to the different tomato cultivars, a high-pressure treatment (400 MPa/25°C/15 min) applied to tomato puree resulted in decreases of vitamin C content and AE value compared with the untreated puree (Sánchez-Moreno et al., 2006b).

3.7. Hydrophobic fraction

The EC\textsubscript{50} and T\textsubscript{EC50} values of the hydrophobic fraction of control were 364 g/g DPPH and 39.0 min, respectively (Fig. 5b). After the cold-break treatment, both EC\textsubscript{50} and T\textsubscript{EC50} values significantly increased 30% and 17%, respectively (p < 0.05). The hot-break treatment induced a decrease of EC\textsubscript{50} value, meanwhile T\textsubscript{EC50} value was unchanged (p > 0.05). Some authors have found that lycopene is the most important compound in the hydrophobic fraction in tomatoes in the ABTS/H\textsubscript{2}O\textsubscript{2}/HRP and DPPH radical-scavenging systems (Cano, Acosta, & Arnau, 2003; Sánchez-Moreno et al., 2006b).

Pressure processing behind 300 MPa at 4 and 25°C maintained the radical-scavenging capacity of tomato juice compared with control due to the values of EC\textsubscript{50}, T\textsubscript{EC50} and AE with no significant differences (p < 0.05). As the pressures were beyond 300 MPa at 4 and 25°C, the AE values of tomato juices significantly increased up to 21% (p < 0.05). Pressure processing (100–500 MPa) at 50°C significantly decreased the AE values of tomato juices compared with that at lower temperatures (4 and 25°C), which indicated that the loss of radical-scavenging capacity was mainly due to the high temperature treatment.

4. Conclusion

Based on the extraction of carotenoids and lycopene, radical-scavenging capacity and inactivation of PME and PG of tomato juice, high pressure processing can be an alternative for hot- or cold-break processing. High pressure processing at 4 and 25°C has almost the same effects on all the processing qualities of tomato juice, however, that at 50°C has less efficiency or even contrary effects. Besides PME and PG inactivation, a 300 MPa treatment improves the extractable carotenoids and lycopene contents and retains the other properties; moreover, pressure treatments at 400 and 500 MPa can improve all the quality attributes in this study. Therefore, a 500 MPa treatment at ambient temperature can be useful in processing tomato juice in considering the inactivation of the enzymes.

This opens new perspectives to produce improved processing qualities of tomato juice products as an alternative for hot- and cold-break processes. The applied conditions require further optimization to mild pressure/temperature combinations, assuring inactivation of microbial and optimal flavor for storage.

Acknowledgments

This study was financially supported by National Science Council, ROC, no. NSC 94-2313-B-040-005.

References


Min, S., & Zhang, Q. H. (2003). Effect of commercial-scale pulsed electric field processing on flavor and color of tomato juice. *Journal of Food Science*, 68(5), 1600–1606.


pressurized orange juice during refrigerated storage. *Journal of Agricultural and Food Chemistry*, 51, 647–653.


