Original paper

Changes in Quality Attributes of Strawberry Purees Processed by Power Ultrasound or Thermal Treatments

Xin-Feng Cheng\(^1\), Min Zhang\(^\ast\) and Benu Adhikari\(^2\)

\(^1\)State Key Laboratory of Food Science and Technology, Jiangnan University, Wuxi, Jiangsu, China
\(^2\)School of Applied Sciences, RMIT University, City Campus, Melbourne, VIC 3001, Australia

Received March 13, 2014 ; Accepted May 1, 2014

The effect of thermal and ultrasound treatments on the physicochemical properties (pH, total soluble solids, titratable acidity, electrical conductivity, viscosity and color attributes), bioactive compounds (ascorbic acid, total pheolics and total anthocyanins) and antioxidant activity of strawberry puree was investigated. No significant difference in pH, total soluble solids and titratable acidity was observed among the treated and control samples whether thermal or ultrasound treatments were used. Ultrasound treatments significantly increased the electrical conductivity, while significantly reducing the viscosity of strawberry puree samples. Ultrasound treatments were found to better maintain or increase the bioactive compounds and the color attributes compared to the thermally treated samples. Ultrasound treatments significantly increased the radical scavenging activity compared to that of the control sample except when the ultrasound treatment was carried out at 0.42 W/mL for 20 and 30 min. These results indicate that ultrasound treatments can greatly improve the quality of strawberry puree.

Keywords: power ultrasound, thermal treatment, strawberry puree, antioxidant activity, phenolic, anthocyanin

Introduction

Strawberry (Fragaria × ananassa Duch.) is a soft, juicy and palatable berry available during the spring-summer period. Strawberry is highly appreciated for its excellent organoleptic properties such as red color, smooth texture, and exquisite taste and flavor. It is also a good source of micronutrients and phytochemical compounds particularly ascorbic acid, anthocyanins and phenolic compounds (Cao \textit{et al.}, 2012). Strawberry is mostly consumed fresh but it is also processed into jams, juice, canned products and added into dairy products such as yoghurt (Terefe \textit{et al.}, 2010). Unfortunately, it is a readily perishable fruit because it is susceptible to fungal attacks and physical damage (Lara \textit{et al.}, 2004). Therefore, it is essential to find a suitable method to extend its shelf-life and maintain its quality for better commercialization.

To date, thermal treatment is the most commonly used technology to inactivate enzymes and destroy microorganisms. However, it also brings about undesirable changes in the food properties, such as loss of nutrients and changes in color, flavor and texture. Therefore, there is a need to develop alternative methods which enhance microbiological stability and to better preserve the nutrients of strawberry. It is expected that ultrasound as one of the novel non-thermal processing technologies can be used as an alternative of the thermal processing (Tiwari \textit{et al.}, 2009c).

In general, ultrasound in 20 – 1000 KHz range can be divided into two zones namely: (1) high frequency (100 – 1000 kHz) low energy ultrasound, (2) low frequency (20 – 100 kHz) high energy power ultrasound (Golmohamadi \textit{et al.}, 2013). When power ultrasound propagates in liquid, cavitation bubbles are generated due to rapid change in pressure. Collapse of these bubbles in the subsequent compression cycles of ultrasonic wave results in localized increase in temperature (5000°C) and pressure (50 MPa), and produces high shearing effects. These extremely high and rapid
changes in the localized temperature and pressure bring about a pasteurisation effect without causing significant rise in macro-temperature (Tiwari et al., 2009b). Power ultrasound has been reported to be effective against foodborne pathogens in fruit juices such as orange juice (Valero et al., 2007), mango juice (Santhirasegaram et al., 2013), apple juice (Abid et al., 2013), guava juice (Cheng et al., 2007), and tomato juice (Adekunte et al., 2010). The application of power ultrasound was also found to better preserve the health promoting functional compounds and other quality parameters of purple cactus pear juices (Zafra-Rojas et al., 2013), apple juice (Abid et al., 2013, 2014), and red raspberry puree (Golmohamadi et al., 2013).

There are several publications on ultrasound processing of fruit juices/purees dealing with various aspects such as inactivation of microbes and anthocyanin stability. However, the effects of ultrasound treatment on the quality parameters (viscosity, total pheolics and antioxidant activity) of strawberry puree have not been reported so far. Therefore, the objectives of the present work were to find out optimum ultrasound treatment parameters for processing of strawberry puree and to evaluate the effects of ultrasound treatment on its quality attributes.

Materials and Methods

Preparation of strawberry puree  Strawberries (Fragaria × ananassa Duch.) were purchased from a local market in Wuxi, China. The strawberries which had uniform size, shape and free from observable decay and damage were selected to prepare the puree. These strawberries were crushed using a domestic juice extractor (JYL-D050, Joyoung Co., Ltd, Hangzhou, China) and then stored in a household refrigerator at 4 ± 1°C until treated by power ultrasound and thermal within 10 h.

Thermal and ultrasound treatments  The strawberry purees were transferred to glass bottles and boiled in water until they achieved a core temperature of 90°C and were held at this temperature for 60 s. This temperature-time combination was selected because thermal treatments for fruit juices or purees generally range from 90 to 95°C for 15 to 60 s. These temperature-time combinations assure at least 5 log reduction in microbial count (Nagy et al., 1993). These thermally treated samples were immediately cooled to ambient temperature by immersing in an ice-water bath.

A 1200 W ultrasonic processor (JY98-IIIN, Ningbo Scientz Biotechnology Co., Ltd, Ningbo, China) with a 15 mm diameter titanium tip was used for ultrasound treatments. The ultrasound probe was submerged to 20 mm within the sample. Sample (160 mL) was transferred in a 200 mL jacketed vessel and was processed at 20 kHz. Applied power levels (10%, 30%, and 50% of maximum equipment power) and treatment times (10, 20 and 30 min) were varied with pulse durations of 5 s on and 5 s off. The acoustic energy density values dissipated into the strawberry puree samples were calculated using Tiwari et al. (2009d)’s method and were found to be 0.17, 0.28 and 0.42 W mL⁻¹ for 10%, 30%, and 50% of the maximum equipment power, respectively. The temperature of the samples was maintained below 40°C during these ultrasound treatments using a recirculating water bath (see Fig. 1).

Physicochemical analysis (total soluble solids, pH, electrical conductivity and titratable acidity)  Total soluble solids were determined using a refractometer (WAY-2W, shanghai INESA & scientific instrument Co., Ltd, Shanghai, China) at 25 ± 1°C and results were expressed in °Brix. The pH values of samples were measured using a digital pH meter (PHS-3C, shanghai INESA & scientific instrument Co., Ltd, Shanghai, China). The electrical conductivity of strawberry puree sample was measured by using a conductivity meter (DDS-11A, Shanghai Rex Xinjing Instrument Co., Ltd. Shanghai, China) at 25°C.

For determination of titratable acidity (TA), ten milliliter sample volume was placed into a 250 mL conical flask and 90 mL
distilled water was added. This solution was titrated with standardized 0.1 N NaOH to the phenolphthalein end point (pH = 8.2 ± 0.1). The volume of NaOH was converted to g malic acid per 100 mL of strawberry puree and TA was calculated using Eq. (1).

\[
TA (\%) = \left[ \frac{V \times 0.1N \times 0.067 \times 100}{m} \right] \quad \ldots \ldots \text{Eq. 1}
\]

where, \(V\) is titre volume of NaOH and \(m\) is mass of strawberry puree (g). All the measurements were performed in triplicate.

**Determination of viscosity**  The viscosity values of strawberry puree samples were measured at 25°C by using a rotary coaxial viscometer (LDV-1 Prime, brook Field Engineering Laboratories, Inc., MA, USA) with S-20 spindle at a shear rate of 10 s\(^{-1}\). Ten milliliter of strawberry puree was used in each run. All the measurements were carried out in triplicate.

**Color measurements**  The color of the strawberry puree samples was measured using a colorimeter (CM-3600D, Minolta, Tokyo, Japan). The coordinates of the color CIE- L* (lightness), a* (redness) and b* (yellowness) of samples were obtained by reflection. Total color difference (TCD) was determined from the coordinates of the color by applying the following equation.

\[
TCD = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \quad \ldots \ldots \text{Eq. 2}
\]

where, \(L_0\), \(a_0\) and \(b_0\) are color values of control sample. Each sample was measured six times. White board was used as the standard reference.

**Determination of ascorbic acid content**  Ascorbic acid content in strawberry puree sample was determined using the standard 2, 6-dichloro-indophenol titration method (Huan and Liu, 2009). Results were expressed as mg per 100 g strawberry puree. All measurements were carried out in triplicate.

**Extraction of Antioxidants**  Ten grams strawberry puree sample was weighed into Erlenmeyer flasks and extracted with 25 mL of methanol solution under stirring for 60 min. Following the mechanical agitation, the samples were centrifuged for 15 min at 2,000 \(\times\) g and 4°C. Ten milliliter of the supernatant was filtered through 0.22 \(\mu\)m poly tetra fluoro ethylene (PTFE) syringe filter and stored at −20°C in aluminum foil covered plastic test tubes for subsequent analysis.

**Determination of total phenolics content**  The total phenolic content of strawberry puree samples was determined by using Folin-Ciocalteu colorimetric method (Stintzing et al., 2005) with slight modification. Briefly, an aliquot (1 mL) of 10% (v/v) Folin-Ciocalteu reagent in distilled water was mixed with 0.2 mL of sample extract. After 5 min, 0.8 mL of a 20% sodium carbonate solution was added. The mixture was equilibrated at 30°C for 30 min and the total phenolic content was immediately measured at 765 nm using a spectrophotometer (UV–visible 2600; Precision Science Instrument, Shanghai, China). Gallic acid was used as standard and the total phenolic content of samples was expressed as mg gallic acid equivalents (GAE) per 100 g samples. All the samples were analyzed in triplicate.

**Determination of total anthocyanins content**  The total anthocyanins content was measured by pH-differential method reported by Lee et al. (2005) with slight modification and using potassium chloride (0.025 M, pH 1.0) and sodium acetate (0.4 M, pH 4.5) buffer systems. Briefly, one milliliter of sample extract was mixed with 9 mL of each buffer solution and the absorbance (Abs) was measured using a spectrophotometer (UV–visible 2600; Precision Science Instrument, Shanghai, China) at 520 and 700 nm, respectively. The total anthocyanins content was calculated using Eq. (3) and expressed as mg pelargonidin-3-glucoside per 100 g samples.

\[
Total \cdot \text{anthocyanins} \cdot (\text{mg}/100\, \text{g}) = \frac{Abs \times MW \times DF \times 100}{\varepsilon \times \lambda \times m} \quad \ldots \ldots \text{Eq. 3}
\]

where \(Abs\) is the difference in absorbance between pH 1.0 and 4.5, \(MW\) is the molecular weight for pelargonidin-3-glucoside (433.0 g mol\(^{-1}\)), \(DF\) is the dilution factor, \(\varepsilon\) is the extinction coefficient for pelargonidin-3-glucoside (22,400 L mol\(^{-1}\) cm\(^{-1}\)), \(\lambda\) is the path length in cm, \(m\) is the sample mass. All the samples were analyzed in triplicate.

**Determination of antioxidant activity**  The antioxidant activity of strawberry puree sample was determined using DPPH assay as described by Patras et al. (2009b) with some modification. Briefly, one milliliter of sample extract was mixed with 2.0 mL of 0.15 mmol L\(^{-1}\) methanolic DPPH solution. The reaction mixture was vortex-mixed and left to stand for 30 min at room temperature in dark. The absorbance at 517 nm was measured using a spectrophotometer (UV–visible 2600; Precision Science Instrument, Shanghai, China). The same procedure was conducted for control without adding sample extract. Total antioxidant activity was expressed as the percentage inhibition of DPPH free radical and was determined by using Eq. (4). All assays were carried out in triplicate.

\[
%\text{DPPH} = \left(1 - \frac{Abs_{\text{sample}}}{Abs_{\text{control}}}\right) \times 100 \quad \ldots \ldots \text{Eq. 4}
\]

\(IC_{50}\) is the concentration of the antioxidant required to cause 50% reduction in the original concentration of DPPH and is used to express the antioxidant activity. \(IC_{50}\) was determined from antioxidant capacity (%) versus extract concentration (µg mL\(^{-1}\)) graph.

**Statistical analysis**  Statistical analysis of the experimental data was carried out by analysis of variance (ANOVA) using SPSS 18.0 software (IBM, Chicago, IL, USA). The significance difference between two means was determined by using Duncan’s test procedure at 95% confidence level \((p < 0.05)\). All the results were expressed as mean ± SD.

**Results and Discussion**

**Total soluble solids, pH and titratable acidity**  The results
regarding the effect of thermal and ultrasound treatments on total soluble solids (°Brix), pH and titratable acidity (TA) in strawberry puree are presented in Table 1. It can be seen from this table that the total soluble solids (°Brix), pH and titratable acidity (TA) values of samples are not significantly different (p > 0.05), irrespective of thermal treatment or ultrasound treatments. These results are in agreement with Abid et al. (2013) for apple juice and with Tiwari et al. (2008a) for orange juice treated with power ultrasound. Similar results were obtained for pasteurized orange juice subjected to high hydrostatic pressure (Bull et al., 2004) and pulsed electric field (Cortés et al., 2008).

**Electrical conductivity and viscosity** Results regarding the effects of thermal and ultrasound treatments on electrical conductivity are listed in Table 1. A significant (p < 0.05) increase in electrical conductivity was observed in samples treated by thermal and power ultrasound compared to the control sample. This increase in electrical conductivity might be attributed to the thermal or ultrasound treatments which cause change in structure of macromolecules and facilitate the release of mineral elements, thus resulting in increase in electrical conductivity. Similar results were obtained by Abid et al. (2014). These authors reported that power ultrasound treated apple juice had slightly higher electrical conductivity values as compared to freshly prepared apple juice (Abid et al., 2014).

**Table 1.** Effect of thermal and ultrasound treatments on total soluble solids (°Brix), pH, titratable acidity and electrical conductivity in strawberry puree sample.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Total soluble solids (°Brix)</th>
<th>pH</th>
<th>Titratable acidity (%)</th>
<th>Electrical conductivity (ms/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>7.90 ± 0.36</td>
<td>3.67 ± 0.02</td>
<td>0.79 ± 0.03</td>
<td>3.03 ± 0.06</td>
</tr>
<tr>
<td>HP</td>
<td>7.60 ± 0.78</td>
<td>3.68 ± 0.04</td>
<td>0.78 ± 0.03</td>
<td>4.06 ± 0.06</td>
</tr>
<tr>
<td>0.17 W mL⁻¹, 10min</td>
<td>7.77 ± 0.42</td>
<td>3.55 ± 0.08</td>
<td>0.78 ± 0.04</td>
<td>3.30 ± 0.01</td>
</tr>
<tr>
<td>0.17 W mL⁻¹, 20min</td>
<td>80.7 ± 0.35</td>
<td>3.61 ± 0.08</td>
<td>0.83 ± 0.11</td>
<td>3.48 ± 0.01</td>
</tr>
<tr>
<td>0.17 W mL⁻¹, 30min</td>
<td>7.77 ± 0.76</td>
<td>3.59 ± 0.06</td>
<td>0.79 ± 0.03</td>
<td>3.73 ± 0.08</td>
</tr>
<tr>
<td>0.28 W mL⁻¹, 10min</td>
<td>8.20 ± 0.85</td>
<td>3.54 ± 0.05</td>
<td>0.82 ± 0.03</td>
<td>3.17 ± 0.08</td>
</tr>
<tr>
<td>0.28 W mL⁻¹, 20min</td>
<td>8.00 ± 0.92</td>
<td>3.57 ± 0.08</td>
<td>0.80 ± 0.07</td>
<td>3.42 ± 0.06</td>
</tr>
<tr>
<td>0.28 W mL⁻¹, 30min</td>
<td>7.87 ± 1.29</td>
<td>3.60 ± 0.14</td>
<td>0.81 ± 0.03</td>
<td>3.78 ± 0.10</td>
</tr>
<tr>
<td>0.42 W mL⁻¹, 10min</td>
<td>8.03 ± 0.35</td>
<td>3.47 ± 0.10</td>
<td>0.79 ± 0.07</td>
<td>3.40 ± 0.12</td>
</tr>
<tr>
<td>0.42 W mL⁻¹, 20min</td>
<td>7.83 ± 0.59</td>
<td>3.58 ± 0.07</td>
<td>0.79 ± 0.03</td>
<td>4.00 ± 0.14</td>
</tr>
<tr>
<td>0.42 W mL⁻¹, 30min</td>
<td>8.03 ± 0.70</td>
<td>3.52 ± 0.16</td>
<td>0.80 ± 0.08</td>
<td>3.97 ± 0.14</td>
</tr>
</tbody>
</table>

Values with different letters within the same column are significantly different (p < 0.05)

Control: freshly or no treatment sample; HP: heat pasteurization (90°C, 60 s).

**Fig. 2.** Changes in viscosity of strawberry puree during thermal and ultrasound treatments. Control: freshly or freshly prepared or untreated sample; HP: heat pasteurization (90°C, 60 s); Bars represent mean ± standard deviation; Different letters above the bars indicate significant differences (p < 0.05)
Fig. 2 shows the effect of thermal and ultrasound treatments on the viscosity of strawberry puree samples. It can be seen from this figure that the thermally treated sample had significantly \( (p < 0.05) \) higher apparent viscosity compared to the non-treated or control sample. This can be ascribed to the effect of the high temperature applied during the thermal treatments (90°C, 60 s). The thermal treatment increases the amount of water soluble pectin fraction due to decrease in proto-pectin and oxalate soluble pectin fraction which results into increase in the viscosity (Contreras et al., 2007). On the contrary, a significant \( (p < 0.05) \) decrease in the viscosity of sonicated samples was observed compared to that of non-treated sample. This decrease in viscosity can be attributed to the formation and collapse of bubbles which leads to the generation of microstreaming, and highly localized variations in pressure and temperature. Similar results have also have been reported in starch-rich materials such as corn, potato, tapioca, and sweet potato (Iida et al. 2013). Reported that ultrasound treated tomato pulp had higher viscosity than that of untreated sample. Bates et al. (2006) also showed an increase in viscosity in sonicated vegetable purees and reasoned that ultrasound treatment enhanced the penetration of moisture into the fibre network which resulted into an increase in viscosity.

**Color attributes** Color is one of the most important visual criteria to which consumers refer with regard to the overall product quality (Tiwari et al., 2009a). Color parameters of strawberry purees as affected by thermal and ultrasound treatments are presented in Table 2. It can be seen from this table that thermal treatment caused a significant \( (p < 0.05) \) decrease in red-green values \( (a^*) \) compared to untreated (control) sample. The color of strawberry fruit is mainly imparted by anthocyanins and the total anthocyanins content was significantly decreased in thermally treated sample (Fig. 5). In addition to thermal degradation of anthocyanins, the loss of color in thermally treated puree sample can also be attributed to increase in the pigment degrading enzymatic reaction by peroxidase and polyphenol oxidase (Patras et al., 2009a). Sonicated samples had slightly lower \( a^* \) values as compared to untreated (control) samples. However, \( a^* \) values for sonicated samples were significantly \( (p < 0.05) \) higher compared to that of thermally treated samples. Likewise, similar extent of color change in sonicated mango juice was reported by Santhirasegaram et al. (2013). Change of color in sonicated samples can be attributed to the extreme physical conditions that prevail during ultrasound treatments. Such extreme conditions also increase the rate of oxidation reactions due to greater interaction with free radicals generated during sonication (Bhat et al., 2011).

Total color difference \( (TCD) \) indicates the magnitude of color difference between thermally treated or sonicated and control samples. According to Tiwari et al. (2008a), TCD values <1.5 indicate “small differences” \( (TCD < 1.5) \) while TCD values between 1.5 and 3.0 \( (1.5 < TCD < 3.0) \) indicate “distinct differences in color change. As shown in Table 2, the TCD values for sonicated samples were significantly \( (p < 0.05) \) lower than those of thermally treated samples. The TCD values of sonicated samples ranged from 0.53 to 3.06 indicating the change in color in these samples ranged from “small” or “distinct”. In contrast, thermal treatment induced much more distinct color change \( (TCD = 4.16) \).

**Ascorbic acid content** Ascorbic acid is one of the commonly used indicators to evaluate the overall nutritional quality of food products (Goula et al., 2006). This is because it is the least stable among all vitamins and is easily destroyed during processing and storage. Loss of ascorbic acid is mainly attributed to its solubility in water and its sensitivity to higher temperatures and oxidative stresses (oxygen, pH and metal ions) (Davey et al., 2000).

As shown in Fig. 3, the ascorbic acid content in untreated and treated strawberry puree ranged from 36.57 – 50.17 mg per 100 g

<table>
<thead>
<tr>
<th>Treatments</th>
<th>( L^* )</th>
<th>( a^* )</th>
<th>( b^* )</th>
<th>TCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>33.54 ± 0.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.30 ± 0.36&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.93 ± 0.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>–</td>
</tr>
<tr>
<td>HP</td>
<td>36.15 ± 0.46&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.16 ± 0.76&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.84 ± 0.68&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.16 ± 0.54&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.17 W mL&lt;sup&gt;-1&lt;/sup&gt;, 10min</td>
<td>33.57 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.27 ± 0.61&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.95 ± 0.20&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.53 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.17 W mL&lt;sup&gt;-1&lt;/sup&gt;, 20min</td>
<td>32.80 ± 0.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.69 ± 0.49&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.16 ± 0.73&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.37 ± 0.18&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.17 W mL&lt;sup&gt;-1&lt;/sup&gt;, 30min</td>
<td>33.09 ± 0.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.02 ± 0.36&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>5.15 ± 0.79&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.59 ± 0.38&lt;sup&gt;abcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.28 W mL&lt;sup&gt;-1&lt;/sup&gt;, 10min</td>
<td>33.12 ± 0.79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.14 ± 0.25&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.34 ± 0.25&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.52 ± 0.30&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.28 W mL&lt;sup&gt;-1&lt;/sup&gt;, 20min</td>
<td>32.13 ± 0.71&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.19 ± 0.87&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>4.66 ± 0.30&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.67 ± 0.69&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.28 W mL&lt;sup&gt;-1&lt;/sup&gt;, 30min</td>
<td>34.76 ± 1.03&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.22 ± 0.54&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>5.49 ± 0.79&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.04 ± 0.36&lt;sup&gt;bde&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.42 W mL&lt;sup&gt;-1&lt;/sup&gt;, 10min</td>
<td>32.40 ± 1.05&lt;sup&gt;d&lt;/sup&gt;</td>
<td>11.87 ± 0.44&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>4.68 ± 0.87&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.85 ± 0.32&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.42 W mL&lt;sup&gt;-1&lt;/sup&gt;, 20min</td>
<td>33.13 ± 0.71&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.21 ± 0.34&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.76 ± 1.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.77 ± 0.17&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.42 W mL&lt;sup&gt;-1&lt;/sup&gt;, 30min</td>
<td>33.09 ± 1.51&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.05 ± 0.36&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.49 ± 0.79&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.06 ± 0.33&lt;sup&gt;ef&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values with different letters within the same column are significantly different \( (p < 0.05) \) \((n = 6)\)

<sup>b</sup>Control: freshly or no treatment sample; HP: heat pasteurization (90°C, 60 s)
samples. These values are consistent with the data reported in earlier publications (Nuñez-Mancilla et al., 2013; Tiwari et al., 2008b). The ascorbic acid content in thermally treated sample was significantly \((p < 0.05)\) lower than that in untreated sample (Fig. 3). The loss of ascorbic acid might be due to its heat-sensitive characteristics. Likewise, Santhirasegaram et al. (2013) also reported that a significant \((p < 0.05)\) decrease in the ascorbic acid content occurred in thermally treated mango juice. In the case of sonicated samples, the ascorbic acid content was significantly \((p < 0.05)\) higher than that in thermally treated sample. This better retention of ascorbic acid content in sonicated samples could be attributed to the reduction of dissolved oxygen which is responsible for degradation of ascorbic acid during cavitation (Cheng et al., 2007). However, a significant \((p < 0.05)\) decrease in the ascorbic acid content was observed when ultrasound treatment was carried out for 20 and 30 min, regardless of ultrasound density. This
increased loss of ascorbic acid could be explained by the formation of free radical in the cavitation bubbles which is associated with oxidative process and also due longer exposure to these free radicals (Tiwari et al., 2009b).

**Total phenolics and total anthocyanins contents** Results regarding the effects of thermal and ultrasound treatments on the total phenolics content of strawberry puree are presented in Fig. 4. As can be seen from this figure the amount of phenolic compounds in the control (untreated) sample was 120.15 mg GAE per 100 g. Thermally treated sample showed a significant ($p < 0.05$) decrease in total phenolics content (13.7% reduction). In contrast, sonicated samples showed better retention or preservation of phenolic compounds when compared to the thermally treated sample. For instance, ultrasound treatments at 0.17 W mL$^{-1}$ and 0.28 W mL$^{-1}$ for 20 min, and at 0.28 W mL$^{-1}$ and 0.42 W mL$^{-1}$ for 10 min showed significant ($p < 0.05$) increase of total phenolics content. Similar results have also been reported by Bhat et al. (2011), who observed an increase in the total phenolics content in sonicated kasturi lime juice samples. The apparent increase in the total phenolics content in sonicated strawberry puree can be attributed to the greater disruption of cell walls and subsequent release of the bound phenolic compounds (Zafra-Rojas et al., 2013). In addition, the removal of occluded oxygen from the strawberry puree by sonication was suggested to contribute to this apparent increase in the phenolic compounds (Masuzawa et al., 2000).

Anthocyanins are bioactive compounds present in many fruits, vegetables and their products. They play important roles in the prevention of neuronal and cardiovascular illnesses, cancer and diabetes, among others (Konczak et al., 2004). Results regarding the effect of thermal and ultrasound treatments on total anthocyanins content are presented in Fig. 5. Thermally treated samples showed a significant ($p < 0.05$) decrease in the total anthocyanins content when compared with the untreated (control) sample. In contrast, sonicated samples showed higher retention of anthocyanins, except in the case of sample treated by power ultrasound at 0.28 W mL$^{-1}$ for 30 min and at 0.42 W mL$^{-1}$ for 20 and 30 min. Abid et al. (2014) reported that sonicated apple juice samples did not show any significant ($p > 0.05$) change in the total anthocyanins content when compared with untreated sample. Yet another study showed higher retention of anthocyanins in strawberry juice when sonicated at amplitude levels and treatment times ranging from 40 to 100% and 2 to 10 min, respectively (Tiwari et al., 2008b). The degradation of anthocyanins, albeit in small amount, during ultrasound treatments can be attributed to various sono-chemical reactions including generation of free radicals and polymerization / depolymerisation reactions (Floros et al., 1994; Tiwari et al., 2009c).

**Total antioxidant activity** The results regarding the effects of thermal and ultrasound treatments on antioxidant activity in strawberry puree samples are shown in Fig. 6. The samples subjected to thermal treatment showed a significant ($p < 0.05$) decrease in the antioxidant activity compared to untreated (control) sample. Interestingly, the sonicated samples had higher antioxidant activity compared to that of the control sample except when the ultrasound was applied at 0.42 WmL$^{-1}$ for 20 and 30 min. It has been reported earlier that ultrasound treatment either increases or maintains the antioxidant activity of foods. For instance, the free radical scavenging activity of purple cactus pear juice was unaffected by ultrasound treatments when applied for 15 and 25 min (Zafra-Rojas et al., 2013). Abid et al. (2013) reported that...
sonicated apple juice had significantly ($p < 0.05$) higher DPPH free radical scavenging activity when compared to the control sample. In general, the antioxidant activity in strawberry puree is the sum of antioxidative activities of all antioxidants, such as phenolic compounds, ascorbic acid, anthocyanins. All of these compounds act as radical acceptors and oxidation chain terminators (Ashokkumar et al., 2008). The increase of antioxidant capacity observed in sonicated samples can be attributed to the increase in phenolics compounds in strawberry puree due to increased extraction and availability of these compounds.

Conclusions

Strawberry puree samples subjected to ultrasound treatments showed significant ($p < 0.05$) increase in the phenolic compounds and antioxidant activity compared to that in untreated (control) sample. The sonicated strawberry puree showed significantly ($p < 0.05$) higher retention of ascorbic acid and anthocyanins compared to the thermally treated (90°C 60s) samples. This study demonstrates that the ultrasound treatment is a better alternative to thermal treatment. Ultrasound treatments at moderate condition can maintain nutritional quality of strawberry puree and could be used in commercial production of better quality products than the thermally processed ones.

Acknowledgements The authors acknowledge the financial support from China National Natural Science Foundation (Contract No. 21176104) which has enabled us to carry out this study.

References


Ultrasound and Thermal Treatments on the Quality of Strawberry Purees


