Physicochemical properties and antioxidant activities of ginger (Zingiber officinale Roscoe) slices according to temperature and duration of hot water treatment

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Abstract

This study was conducted to determine the optimal hydrothermal pretreatment conditions for manufacturing processed ginger products. Ginger slices heated at different temperatures (60-100°C for 1 h) for varying durations (1-5 h at 80°C) were compared in terms of their physicochemical properties, antioxidant activities, and functional compound contents. The pH and soluble solid content decreased with increasing hydrothermal treatment temperature. Browning occurred at temperatures > 80°C. The 2,2-diphenyl-1-picrylhydrazyl and 2,2’-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging were highest after heating at 80°C for 1 h, and the total phenolic compound content showed a similar trend. As the hydrothermal treatment temperature and duration increased, the 6-gingerol content decreased and the 6-shogaol content generally increased. Based on sensory testing of ginger jeonggwa (with sugar syrup) prepared using hot water-treated ginger slices, the optimal hot water treatments were conducted at 70 and 80°C for 1 h, with no significant difference between these temperatures in terms of smell, taste, and texture. Therefore, hydrothermal treatment of ginger at 70-80°C for 1 h was suitable to improve the functionality and antioxidant ability while maintaining the sensory quality. Therefore, this may be used in the production of processed ginger.

Keywords: ginger slice, hydrothermal treatment, 6-shogaol, antioxidant capacities, optimal pretreatment condition

Introduction

Ginger (Zingiber officinale Roscoe) is a perennial herbaceous plant of the Zingiberaceae native to subtropical and tropical regions, and it is grown in tropical and subtropical regions in China, India, Egypt, and Iraq (Lee et al., 2011). In Korea, ginger is mostly produced in Andong and Yeongju of the North Gyeongsang province and Seosan and Dangjin of the South Chungcheong province (Lee and Kim, 2016). The ginger root and stalk feature a unique spicy taste and aroma...
and are distributed as fresh ginger, dried ginger, and ginger oil, which are widely utilized as food, medicine, and cosmetics (Lee et al., 1979; Lee et al., 1996). Further, ginger is not only used as a spice worldwide but has been proven to have pharmacological efficacy, based on which it is utilized as digestive aid, medicine for nausea, abdominal pain, low back pain, and diarrhea, and antibacterial agents (Kim et al., 2001). Past studies have compared the constituents (Chung et al., 1996) and amino acid composition of ginger according to the growing regions (Takahashi et al., 1982), and studies have also investigated the spicy component (Chen et al., 1986) and aromatic component that is closely related to the flavor of ginger (Moon et al., 1997). Ginger has a moisture content of 80-90%, and starch accounts for 40-60% of the entire solid mass (Kim et al., 1991; Shin et al., 1994). The major ingredients of ginger include carbohydrates, ketones, alcohols, and volatile aromatic components, such as zingiberene and γ-cadinene. Ginger consists of 0.1-0.3% of oil, and the main ingredients of this oil, the 6-gingerol and 6-shogaol homologues, give ginger its characteristic potent spice, with their content markedly higher than that of other trace ingredients. For this reason, 6-gingerol and 6-shogaol are frequently used as quality indices during storage and distribution of ginger, and they have attracted much attention as potential ingredients of functional foods owing to their antioxidant and anti-inflammatory properties (Connell et al., 1969; Connell et al., 1970). Particularly, 6-gingerol has an antioxidant activity of equivalent to 95% of that of ascorbic acid (Lee et al., 2006), and as it stabilizes β-carotene (Lee et al., 1985), many studies have investigated its antioxidant (Chang et al., 1994), anti-cancer (Surh et al., 2002), and anti-bacterial (Ippoushi et al., 2003) effects. With its pharmaceutical effects documented, ginger, along with various herbs, is utilized in developing health supplements and crude drugs.

Ginger is generally harvested in October and November and stored and distributed throughout the year. However, ginger has poor storability, as it is susceptible to chilling injury at a temperature of 10°C or lower and is susceptible to germination (Emmaya et al., 1981), mold growth, surface drying, and softening at a temperature of 18°C or higher (Jo et al., 1996). In Korea, 58,947 tons of ginger was produced in 2016, with the production growing at an annual rate of about 15.4%, and the ginger market size is about 535.9 billion KRW, also growing at an annual rate of 14.2% (Chungcheongnam-do Agricultural Research and Extension Services, 2017), indicating growing demands. To address the challenges of ginger storage and increase the diversity of ginger consumer products, past studies have investigated the optimal quality characteristics of sweet-rice muffins containing ginger powder (Lee et al., 2011), rheological characteristics of pound cake containing ginger powder (Chung et al., 2012), quality characteristics of ginger juice-added muffins (Han et al., 2012), quality characteristics of apple jams made with ginger (Lee et al., 2014), quality characteristics of all-purpose flour containing ginger powder (Lee et al., 2021), and cookies containing ginger powder (Kwon et al., 2021). In terms of processed ginger, candied ginger accounts for nearly half of all processed ginger products (KAMIS). Jeonggwa (candied snacks) is a traditionally Korean snack prepared by lightly boiling plant roots, stalks, or fruits to soften the flesh and slowly braising it in sugar or honey (Kim, 1999). Ginger has a potent spicy flavor, so eliminating the spicy flavor during the candying process is more important for ginger than other types of jeonggwa. Ginger is generally treated with hot water to remove its pungent flavor, and during this process, its active ingredients are lost, and it may be browned or discolored.

While several studies have explored measures to enhance the storability of ginger and ginger-containing processed food products, studies on hydrothermal treatment, an essential step in producing candied ginger, are lacking. Thus, this study applied hydrothermal treatment to ginger slices at varying temperatures and durations and analyzed the changes in physicochemical, functional, and sensory characteristics to identify the optimal conditions for hydrothermal treatment that do not impair the quality of processed ginger products. The results of this study would be useful as basic data for producing processed products using ginger.

**Materials and method**

**Materials and hydrothermal treatment**

For this experiment, ginger produced in Seosan, South Chungcheong Province that are similar in color and size and has no blemishes. Ginger washed in running water was cut into 0.4-cm slices using a vegetable cutter (RG-100, Hallde,
Kista, Sweden). The ginger slices were placed in a water bath (WMB-311, Daihan Scientific, Seoul, Korea) with water at a 1:10 (w/v) ratio and heated at 60°C, 70°C, 80°C, 90°C, and 100°C for 1 h. For the evaluation of suitability for food processing by temperature of hydrothermal treatment, the temperature was fixed to 80°C, which was the temperature at which the best results were obtained in the functional ingredient experiment, and to establish the optimal duration of hydrothermal treatment, ginger and water were heated in a water bath (WMB-311, Daihan Scientific, Seoul, Korea) at a 1:10 (w/v) ratio for 1 h, 2 h, 3 h, 4 h, and 5 h. The ginger slices were taken out immediately after the hydrothermal treatment and drained for an analysis of the characteristics.

**Physicochemical quality characteristics**

For the pH and soluble solid content analysis, the hydrothermal-treated ginger slices were immersed in distilled water of a volume fourfold greater than the sample and ground using a homogenizer (AM-9, Nihonseiki Kashima Co., Ltd., Tokyo, Japan). The pH of the prepared sample was measured using a pH meter (pH 510 Benchtop Meter, Oakton Instruments, IL, USA), and the dilution factor was not reflected in the pH value. Soluble solid content was measured using a refractometer (Master-a, ATAGO Co., Tokyo, Japan) and presented as °Brix, and the dilution factor was not reflected in the measurement. Color was analyzed by arbitrarily choosing 10 samples from each treatment group and making three repeated chrominance measurements at the center of a cross-section of the ginger slices. The average value was used, and a colorimeter (CR-400, Konica Minolta Co., Osaka, Japan) calibrated with a standard white plate (L*=-97.79, a*=-0.38, b*=-2.05) was used. The color difference between pre- and post-treatment samples was calculated using the following equation:

\[
\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}
\]

**Antioxidant activity**

A modified version of the Blois method (Blois et al., 1958) was used for the 1,1-diphenyl-2-picrylhydral (DPPH) radical assay. The sample was prepared through ultrasound-assisted extraction of the ginger slices in 80% ethanol (40 kHz, Daihan Scientific Co., Ltd., Seoul, Korea) for 30 min at room temperature (20±5°C) and four rounds of filtration with Whatman filters. 0.4 mM DPPH (Sigma- Aldrich, MO, USA) solution was adjusted with ethanol to achieve an absorbance of 0.95-0.99 and mixed with the sample solution at 4:1 ratio. After incubating the mixture for 10 min, absorbance was read at 517 nm using a UV-Visible spectrophotometer (Evolution 201, Thermo Fisher Scientific, MA, USA), and the DPPH radical scavenging activity was computed using the following equation:

\[
\text{DPPH radical scavenging activity}(\%) = \frac{\text{Blank absorbance - Sample absorbance}}{\text{Blank absorbance}} \times 100
\]

ABTS radical scavenging activity was measured with reference to the method proposed by Re et al. (1999). 7.4 mM ABTS was mixed with 2.45 mM potassium persulphate (Sigma-Aldrich, MO, USA) at 1:1 ratio and incubated for 14 h in dark to form cation radicals (ABTS·⁻). The solution was then diluted such that the absorbance value is below 1.00 at 734 nm. 20 µL of sample solution was added to 980 µL of the diluted ABTS⁻ solution and incubated for 10 min before reading absorbance. The result was presented as Trolox equivalent (µM) using Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid; Sigma-Aldrich, MO, USA) as the standard substance.

**Total phenol content**

Total phenol content (TPC) was quantified based on the Folin-Ciocalteu method (Benvenuti et al., 2004). The sample was prepared through ultrasound-assisted extraction of the ginger slices in 80% ethanol (40 kHz, Daihan Scientific Co., Ltd., Seoul, Korea) for 30 min at room temperature (20±5°C) and four rounds of filtration with Whatman filters. 1 mL of the sample solution was mixed with 1 mL of Folin-Ciocalteu reagent (Junsei Chemical Co. Ltd., Tokyo, Japan), incubated for 15 min, mixed with 1 mL of 10% Na₂CO₃ 1 mL (Duksan Pure Chemicals Co., Ansan, South Korea) and incubated for another 60 min in dark. Absorbance was measured at 700 nm using a UV-Visible spectrophotometer (Evolution 201, Thermo Fisher Scientific, MA, USA), and the TPC was presented as tannic acid equivalent (TAE) mg/L using tannic acid (Chameleon Chemicals, Osaka, Japan) as the standard substance.
6-Gingerol, 6-shogaol contents

To analyze the 6-gingerol, 6-shogaol contents of hydrothermal-treated ginger slices, the sample was prepared through ultrasound-assisted extraction in 80% methanol (40 kHz, Daihan Scientific Co., Ltd., Seoul, Korea) for 30 min and filtration through a 0.45-μm membrane filter. The methods proposed by Gorecki et al. (1997) and He et al. (1998) that enable simultaneous analysis of 6-gingerol and 6-shogaol were applied to perform high performance liquid chromatography (HPLC) (Model Prominence, Shimadzu, Kyoto, Japan). The YMC-Peak Pro C18 (4.6×250 nm, 5 μm, 120 Å) was used as the column, with the temperature set at 30°C. A gradient system with water and acetonitrile was used for the mobile phase. The flow rate was set at 1.0 mL/min, and the volume of sample injection was set at 20 μL.

Sensory evaluation

Sensory evaluation was performed by 15 adequately trained graduate students of the Gyeongbuk National University. The samples for the sensory evaluation were prepared by mixing the ginger slices treated at each experimental condition with sugar at a 2:1 ratio and braising it for about 40 min at 80°C. The evaluation consisted of color, appearance, odor, taste, ginger taste, hardness, chewiness, and overall preference using a five-point scale.

The students were instructed to mark 1 for low preference due to off-taste and off-flavor and to mark 5 for high preference. The sensory evaluation was exempted for review by the Institutional Review Board at Gyeongbuk National University (Application number: 2021-0096) and proceeded safely.

Statistical processing

All experimental measurements were taken three times, and the results were presented as mean and standard deviation (mean±SD). The results were analyzed with ANOVA and Duncan’s multiple range test (p<0.05) using the SAS program (SAS 9.4, SAS Institute, Inc., Cary, NC, USA).

Results and discussion

pH and soluble solid content

Table 1 shows the pH and soluble solid contents of ginger slices by heating conditions. The pH of ginger slices tended to decrease with increasing temperature of hydrothermal treatment and with increasing duration of hydrothermal treatment. This is consistent with previous findings that pH decreased with increasing temperature of thermal treatment of bellflower (Platycodon grandifloras) (Song et al., 2018). Kim et al. (2014) reported that hydrothermal-treated carrots

Table 1. Physicochemical properties of heat-treated ginger slices under various temperature and time conditions

<table>
<thead>
<tr>
<th>Samples</th>
<th>pH</th>
<th>Soluble solid contents (°Brix)</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.26±0.09&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>0.93±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>82.97±3.02&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>-4.61±1.05&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>48.97±3.96&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>60</td>
<td>6.33±0.03&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.77±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>85.36±1.60&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-7.18±0.83&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>47.80±3.76&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>70</td>
<td>6.26±0.02&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>0.63±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>83.67±2.94&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>-7.63±0.45&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>46.30±4.19&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>80</td>
<td>6.21±0.01&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.43±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>77.50±5.26&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-7.99±0.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44.76±4.67&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>73.54±4.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-6.69±1.02&lt;sup&gt;c&lt;/sup&gt;</td>
<td>44.70±6.23&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
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<td>0.17±0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>69.83±2.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-4.81±1.36&lt;sup&gt;de&lt;/sup&gt;</td>
<td>43.90±4.55&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>Time (h)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>60</td>
<td>1</td>
<td>6.21±0.01&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.43±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>77.50±5.26&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-7.99±0.78&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
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<td>2</td>
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<td>0.23±0.06&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>81.21±3.91&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-6.70±1.15&lt;sup&gt;eh&lt;/sup&gt;</td>
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<td>3</td>
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<td>0.20±0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>78.19±3.83&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>-6.62±1.13&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>4</td>
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<td>0.10±0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75.55±5.45&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-5.30±1.44&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>100</td>
<td>5</td>
<td>6.32±0.03&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.10±0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>76.28±5.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-4.11±1.47&lt;sup&gt;f&lt;/sup&gt;</td>
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</tbody>
</table>

<sup>1</sup>Temperature treatment, 1 h; time treatment, 80°C.
<sup>2</sup>Mean±SD (n=3) with different letters are significantly different (p<0.05).
had the lowest organic acid content compared to carrots with other types of pretreatment (steaming, stir frying). This was speculated to be due to the possibility that organic acids were volatilized by heat or were extracted into the hot cooking water (Lee and Jung, 2012). Further, this result was similar to the report by Lee et al. (2005), where pH increased over time after hydrothermal immersion treatment as organic acids were extracted. In general, pH change is closely linked to organic acid content and is used as a marker of biochemical change, and it has been reported that prolonged thermal treatment at high temperatures facilitates the biochemical changes of ginger (Chung et al., 2009). Soluble solid content of ginger slices significantly decreased with increasing temperature and duration of hydrothermal treatment. This is in line with the results of Lee et al. (2015) that total sugar content of burdock declines with steaming due to the extraction of water-soluble sugar ingredients and that of Yoon et al. (2005) that the soluble solid content of heat-treated ginseng decreases with increasing temperature and duration of heating.

**Color and discoloration**

Table 1 shows the color (CIE L*a*b*) results of heated ginger. The L* value significantly decreased with increasing temperature of hydrothermal treatment but did not differ according to the duration of hydrothermal treatment. The a* value decreased below that of non-treated samples with weaker heat treatment, resulting in a greenish color. However, the value increased to a level comparable to the non-treated samples with increasing temperature and duration of hydrothermal treatment. In other words, weak hydrothermal treatment can actually cause ginger to develop a greenish color. The b* value significantly decreased with increasing temperature and duration of hydrothermal treatment. Curcumin, the yellow pigment found in ginger, is insoluble in cold water but dissolves well in warm water and is vulnerable to heat (Kim, 2007). Thus, the extraction of curcumin into the hot water seems to have resulted in a lower b* value of ginger slices (Jung et al., 2004; Jung et al., 2012). Fig. 1 shows the ΔE and browning index (BI) of the non-treated sample and treated samples. The ΔE value significantly increased from 6.59 to 15.15 with increasing treatment temperature but did not markedly change according to the duration of treatment. Considering that there were no significant changes when the temperature was fixed at 80°C and durations of treatment were extended, the surface color of ginger seems to be more heavily influenced by the temperature of treatment rather than the duration of treatment. Regarding the BI, the BI was lower than the non-treated group when treated with 60-80°C for 1 h, but the index increased to a similar level to that of the non-treated group when the temperature was increased to 90°C or higher. When the temperature was fixed to 80°C and the duration was varied, the range of BI was significantly lower (45.90-48.27) than the non-treated group, with no significant differences among the treated groups. These results were similar to that of Kang and Hyun (2007), where curcumin content did not significantly differ according to the duration of water extraction of turmeric (30-180 min) but did significantly differ according to the temperature of extraction. As shown in Table 1, the L* value is more sensitive to the temperature of treatment, rather than the duration of treatment, where it markedly decreases at higher temperatures, thereby also affecting the BI. Jo et al. (1996) reported that browning of ginger generally is due to the Maillard reaction primarily involving fructose and asparagine and nonenzymatic browning involving the oxidation of...
ascorbic acid, and that the brightness value decreased. Chun et al. (1986) showed that when glucose+glycine solution and fructose+glycine solution were heated at varying temperatures, the Maillard reaction was dramatically facilitated from a temperature of about 90°C.

In conclusion, treatment with hot water at 60-80°C facilitated the extraction of curcumin into the hot water, resulting in a brighter color or lower BI compared to the non-treated samples. However, hydrothermal treatment at a temperature of 90°C or higher triggered the Maillard reaction and caused browning.

**Antioxidant activity and TPC**

Table 2 shows the DPPH and ABTS radical scavenging activities and TPC by heating condition. DPPH radical scavenging activity of ginger slices increased with increasing temperature of hydrothermal treatment and peaked at 80°C, after which it declined. This is similar to the results of Ross et al. (2011), where radical scavenging activity increased proportionally to heating temperature and duration and then decreased from a certain point. The decreasing DPPH radical scavenging activity with increasing duration of heat treatment is speculated to be due to the extraction or alteration of the active ingredients of ginger slices as a result of extended heat treatment. Further, based on the degree of change, DPPH radical scavenging activity seems to be more heavily influenced by the temperature of treatment than duration of treatment. The ABTS radical scavenging activity of ginger slices increased with increasing temperature of heat treatment and peaked at 80°C (596.91 μM), after which it declined. The scavenging activity decreased with increasing duration of heating, similar to the results of DPPH radical scavenging activity. The higher ABTS radical scavenging activity compared to the DPPH radical scavenging activity is reported to be due to the difference in the radical-eliminating mechanisms and substrate binding (Re et al., 1999). The TPC of ginger slices was the highest at 80°C and tended to decrease with increasing duration of hydrothermal treatment. This is similar to the results of Kim et al. (2008), where TPC of fruits and vegetables increased with increasing temperature of heat treatment and decreased from a certain point. Yoon et al. (2005) reported that phenolic compounds were more easily extracted from ginseng with higher heating temperature and duration and that insoluble phenolic compounds were isolated from high-molecular compounds and degraded to free phenolic compounds, consistent with the findings of this study. Furthermore, DPPH and ABTS radical scavenging activity and TPC were higher at a temperature of 80°C or higher early in the heating (1st h) compared to the control (raw ginger), presumably due to an elevation of melanoids, a brown product of the Maillard reaction (Do et al., 1989). However, as prolonged heat

<table>
<thead>
<tr>
<th>Samples</th>
<th>DPPH (%)</th>
<th>ABTS (μM)</th>
<th>TPC (mg/L)</th>
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<tbody>
<tr>
<td>Control</td>
<td>27.22±2.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>225.63±20.56&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.68±3.49&lt;sup&gt;bc&lt;/sup&gt;</td>
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<tr>
<td>Temperature&lt;sup&gt;[1]&lt;/sup&gt; (℃)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>60</td>
<td>20.90±1.27&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>135.63±8.04&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>80</td>
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<td>56.05±0.88&lt;sup&gt;bcd&lt;/sup&gt;</td>
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<td>484.52±21.27&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45.49±2.11&lt;sup&gt;cd&lt;/sup&gt;</td>
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<td>333.41±43.81&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.03±4.87&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Time (h)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1</td>
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<td>3</td>
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<td>4</td>
<td>45.64±3.51&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>39.67±1.14&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>48.98±4.65&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>453.04±19.51&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.48±1.40&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>[1]</sup>Temperature treatment, 1 h; time treatment, 80°C.
<sup>[2]</sup>Mean±SD (n=3) with different letters are significantly different (p<0.05).
treatment may actually break down phenol components (Kim et al., 2014), and antioxidant substances are released into the hot water, the TPC may be lower after long heat treatment compared to the earlier values. In conclusion, the antioxidant capacity and TPC of ginger slices were more substantially influenced by temperature changes than the duration of treatment, with the values peaking after 1 h of treatment at 80°C.

6-Gingerol, 6-shogaol contents

Table 3 shows the 6-gingerol and 6-shogaol contents, the major functional ingredients, of ginger following hydrothermal treatment. 6-gingerol content was the highest in the 70°C group (215.55 mg/L) and began to decrease from 80°C with the lowest content in the 100°C group (95.77 mg/L). This is similar to the results of Bhattacharai et al. (2001) that 6-gingerol content decreases at high temperatures because it is converted to 6-shogaol at high temperatures. 6-Gingerol prevents phospholipid oxidation by the iron chloride ascorbate (FeCl₂-ascorbate) system and inhibits xanthine oxidase, an enzyme that contributes to the formation of reactive oxygen species such as superoxide anions (Lee et al., 2006). 6-Shogaol is produced by dehydration of gingerol and has been reported to have biochemical effects such as antibacterial and antioxidant effects. The 6-shogaol has been reported to have superior anti-inflammatory, antioxidant, and anti-cancer effects compared to 6-gingerol (Chang et al., 1994). 6-Shogaol content remained unchanged at low temperatures but increased at higher temperatures, peaking at 100°C (15.87 mg/L). It also significantly increased with increasing duration of heating, with the highest content (16.71 mg/L) in the 5 h group. These results are similar to those reported by Ok et al. (2012), where 6-shogaol content of ginger increased with increasing drying and extraction temperatures. Further, Cheng et al. (2011) also reported that 6-shogaol content increases with decreasing 6-gingerol content and is inversely proportional to the degree of exposure to heat during processing. Therefore, the temperature or duration of hydrothermal treatment should be raised to increase the content of 6-shogaol, a functional ingredient, in ginger.

Sensory evaluation

Table 4 shows the results of sensory evaluation of candied ginger prepared by braising hydrothermal-treated ginger slices with sugar at a 2:1 ratio. The appearance preference score for the control group was 3.5, and the sample with the highest preference score for appearance was the ginger hydrothermal treated at 60°C for 1 h. Similarly, the preference for color was also the highest for the 60°C treatment group, followed by control group, 70°C group, 80°C group, 100°C group, and 90°C group. Ginger slices treated at higher temperatures and for longer durations would have had the Maillard reaction involving sugars and amino acids that causes browning (Kim et al., 2018), which would have contributed to less preferred appearance and color. The preferences for odor, taste, ginger taste, hardness, chewiness, and overall preference did not significantly differ according to the conditions of hydrothermal treatment. In terms of the duration of heating, the 2 h group was rated to have the most preferred appearance and color, and the preference score tended to decrease with increasing duration of treatment beyond this point. On the other hand, there were no significant trends observed for odor, taste, and chewiness. The sample treated at 80°C for 5 h was given a markedly lower score for ginger taste and overall preference. The browning caused by longer duration and higher temperature of heating led to significantly different color, and particularly, browning caused by long pre-treatment influenced the
요 약

본 연구에서는 열처리 시 생강편의 이화학적 변화와 기능성 성분의 변화를 평가하여 생강 가공품 생산의 기초 자료를 제공하고자 하였다. 열처리된 생강편의 pH는 열처리 전의 온도가 증가함수록 감소하였고 시간에 따라 경향성은 나타나지 않았다. 생강편의 가용성 고형분 함량은 열처리 온도와 시간이 증가함에 따라 유의적으로 감소하는 경향을 나타내었다. 생강편의 L* value와 b* value는 열처리 온도와 시간이 증가함에 따라 유의적으로 감소하는 경향을 나타내었고 a* value는 증가하였다. 갈변도 산출해 본 결과에서는 1시간 동안 열처리 시 80°C 이상에서 갈변이 발생하였다. 생강편의 DPPH, ABTS 라디칼 소거능은 80°C에서 1시간 가열한 경우가 가장 높게 나타났으며, 그 이상으로 열처리 시간이 길어지면서, 온도가 높아질수록 감소하는 경향을 보였다. 생강편의 총 탈색성 화합물 함량 또한 항산화능 실험 결과와 유사한 경향을 나타내었다. 열처리 시간과의 시간이 증가함수록 6-gingerol 함량은 감소하였으며 6-shogaol 함량은 증가하는 경향을 나타내었다. 다양한 조건으로 열처리된 생강편으로 생강경과를 제조하여 관능검사를 수행한 결과, 종합적 기호도는 70°C와 80°C에서 1시간 동안 열처리된 것이 가장 높았으며, 냉세나 맛, 식감 부분에 있어서는 기호도에 유의미한 차이가 없었다. 이상의 실험 결과로 보아 생강은 열처리 시간보다 온도에 민감하게 반응하였으며, 생강을 1시간 동안 70-80°C에서 열처리하는 것이 관능적 평점은 유지하면서 기능성과 항산화능을 향상시킬 수 있는 조건이었다. 이는 가공품으로 제조되기 전 적절한 전처리로 활용될 수 있을 것으로 사료된다.
Conflict of interests
The authors declare no potential conflict of interest.

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