Technical paper

Improvement of the Bitterness and Astringency of Green Tea by Sub-Critical Water Extraction

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Green tea is known for its high content of functional catechins and is commonly consumed for its health-promoting effects. However, green tea catechins are highly bitter and astringent, and thus the development of products that can be consumed regularly is necessary for their efficient, routine intake. The aim of this study was to use sub-critical water extraction (SWE) to produce a green tea extract both less bitter and less astringent than typical green tea. Results from chemical evaluation using a taste sensor analyzer indicated that SWE reduced bitterness, astringency and unpleasant taste while it retained the original fragrance in the green tea extract. Furthermore, the SWE-produced extract had higher amounts of arginine and water-soluble pectin, which are thought to mask the bitterness and astringency of green tea.

Keywords: sub-critical water extraction, green tea, catechin, bitterness, astringency, taste sensor analysis, differential odor analysis, water-soluble pectin

Introduction

Green tea (Camellia sinensis L.) has been consumed for its health benefits since ancient times in a wide range of countries, including Japan and China. Many of its favorable effects have recently been ascribed to catechins, which have begun to attract global attention as components with physiological functions, including antioxidant (Miura et al., 1994; Yokozawa et al., 2000), antibacterial (Gradisar et al., 2007), cancer-suppressing (Friedman et al., 2007), and cholesterol-reducing (Bursill et al., 2007) effects. The demand for green tea-based drinks in the maintenance and promotion of health is increasing. Today, many kinds of green tea are packaged in PET bottles and marketed, with some containing a high level of functional catechins. However, as green tea catechins are characterized by strong bitterness and astringency, the development of products that can be consumed regularly is necessary for their efficient, routine intake. To date, research papers and patents concerning processing techniques, such as the masking of bitterness and astringency using cyclodextrin (Okamura et al., 2008, 2009; Hayashi et al., 2010) and the suppression of bitterness and astringency with the addition of chitosan complex and soy milk protein, have been reported. However, the intrinsic taste and flavor of green tea may be impaired and the cost of manufacturing may be increased due to additives such as protein and chitosan. Therefore, we attempted to improve the taste and aroma of green tea by sub-critical water extraction (SWE), which has rarely been applied to food processing and does not require additives. Conventionally, green tea extracts containing high catechin levels have been obtained by hydrothermal extraction (pressurized extraction), enzyme reaction extraction (Anan et al., 1981; Yoshida et al., 1999), or solvent extraction using alcohol, methanol, etc. However, these techniques have a number of disadvantages, such as requiring a prolonged extraction time at high temperatures to ensure a high extraction rate, as well as the increased risk and handling difficulty associated with using enzymes or organic solvents. In addition, these processes can negatively affect the extraction of flavor components, which are vital to the palatability of green tea. In contrast, SWE is relatively free of such undesirable effects and is thus considered to be advantageous for tea extraction.
SWE is carried out while maintaining the liquid state at a high temperature and pressure. It provides excellent extraction performance and a strong hydrolyzing effect (Khajavi et al., 2005; Wiboonsorikul et al., 2007a, 2007b; Hata et al., 2008; Murayama et al., 2009; Tangkhavanich et al., 2012). Water reaches a critical point at 374°C and 22 MPa. Water at a temperature or pressure above this critical point is called super-critical water, and water at a temperature and pressure below this critical point is called sub-critical water (Herro et al., 2006). Water shows unusual properties, including an altered dielectric constant and ionic products, when its temperature and pressure are changed, and is expected to be useful as a solvent that provides unprecedented reaction mechanisms. Furthermore, this process uses common water and is harmless to both the body and the environment. Previous studies have reported food processing using SWE (Kulkarni et al., 2008a, 2008b; Etoh et al., 2010); however, many aspects of SWE remain unclear and further evaluation is necessary for its effective use. It is essential to gather knowledge about the fundamental aspects of SWE in order to apply it to the production of new palatable green tea products and the future development of other foods. In this study, we compared SWE to conventional heated water extraction and pressurized extraction. In addition, we simultaneously evaluated differences in the taste and flavor of green tea extracts from each extraction method (Hattori et al., 2003). Sensory evaluation results suggested that the strong unpleasant taste peculiar to catechins was decreased by SWE. In addition, we scientifically clarified the above results using taste sensor analysis (Uchiyama et al., 2011) and differential odor analysis. Furthermore, we analyzed the protein, amino acid, total sugar, water-soluble pectin, various catechin and caffeine content of green tea extracts to elucidate the bitterness and astringency mechanisms of catechins.

Materials and Methods

Reagents

Green tea leaves were purchased at a specialty tea store. Epigallocatechin gallate (EGCG), epicatechin gallate (ECG), epigallocatechin (EGC), epicatechin (EC), gallocatechin gallate (GCG), catechin gallate (CG), gallocatechin (GC), catechin(C), and caffeine were purchased from Wako Chemical Co., Osaka, Japan. Amino acid standard mixture and pectin were also purchased from Wako Chemical.

Green tea extraction method

Experimental samples were prepared by extracting 18 g organic tea leaves produced in 2010 with 360 mL water after stirring for 3 min. Extraction was performed by hydrothermal extraction, pressurized extraction, and SWE. With hydrothermal extraction, tea leaves were boiled at 90°C for 10 min, and the extract was allowed to cool to room temperature. In pressurized extraction, tea leaves were boiled at 0.2 MPa and 120°C for 15 min, and the extract was allowed to cool to room temperature. In SWE, the pressure and temperature were raised to 3.0 MPa and 130°C for 1 min, and the extract was rapidly cooled in coolant water. The green tea extracts obtained by the three methods were passed through No. 2 filter paper, and the resultant filtrates were used as samples for subsequent analyses. The samples were stored in air-tight containers at −30°C and thawed immediately before the experiments.

Measurement of total catechin content

Catechins were quantified by the colorimetric method using iron tartrate. An iron tartrate reagent was prepared by dissolving 500 mg ferrous sulfate and 2.5 g sodium potassium tartrate in water and adjusting the volume to 500 mL. Phosphate buffer was prepared by mixing M/15 disodium phosphate and M/15 monopotassium phosphate with a stirrer and adjusting the pH to 7.5. Five mL of a sample was mixed with 5 mL of the iron tartrate reagent, the volume of the mixture was adjusted to 25 mL using the phosphate buffer, and an absorbance at 540 nm was determined (Maeda-Yamamoto et al., 2005). The catechin content was calculated based on the amount of gallic acid ethyl determined from the sample absorbance, in relation to a calibration curve.

Organoleptic evaluation of green tea extracts

The catechin content of the green tea extracts obtained by hydrothermal, pressurized, and SWE methods was adjusted to 180 mg/100 mL, and organoleptic testing was performed by tasting and smelling. To discern differences in the unpleasant taste more clearly, the level of catechins in the specimen was three times higher than that in a cup of green tea typically consumed. In a blind tasting, 15 researchers from the green tea industry evaluated the bitterness, astringency, drinkability, and aroma of extracts obtained by various methods to judge their superior and inferior qualities. The subjects independently performed the sensory assessments, and ease of drinking was ranked. The same score was assigned to samples that were judged as having the same drinkability. After calculating the mean ranking order of the result, we ascertained the differences among the three green tea extracts.

Evaluation of astringency using a taste sensor

After standardizing the catechin content, 50 mL samples of the green tea extracts obtained by hydrothermal, pressurized, and SWE were placed in special cups and analyzed using a taste sensor (SA402B; Intelligent Sensor Technology, Kanagawa, Japan). Bitterness (C00), astringency (AE1), tastiness (AAE), saltiness (CT0), and sourness (CA0) were evaluated using the sensor. Both the “initial taste”, the taste perceived the moment the drink was placed in the mouth, and the “last taste”, the taste perceived after the drink was swallowed, were evaluated. The potential of the reference solution was
regarded as zero, and the difference in the potential of the sample was measured as the initial taste. The sensor was then rinsed gently, and the difference in the potential on re-measurement of the reference solution was determined as the last taste. The measurement was performed three times for each sample, and the means of the sensor outputs were calculated. The green tea extract obtained by hydrothermal extraction was used as the reference sample (Hayashi et al., 2006).

Aroma evaluation using differential odor analysis The aroma of green tea extracts obtained by hydrothermal, pressurized, and SWE methods was analyzed using a differential odor analyzer (FF2020S; Shimadzu Techno-Research, Kyoto, Japan). Evaluation of the samples was performed by expressing the sensor outputs from the 10 oxidized semi-conductor odor sensor elements mounted on the analyzer, in reference to measurements of nine reference gases, and visualized using presentation software. The odor index and similarity among samples were numerically expressed, and the quality and strength of odors were compared among the samples by preparing radar charts. Analysis was performed by placing 30 mL of a sample in a 2 L polyethylene terephthalate (PET) bag confirmed to be odorless after washing; the bag was then sealed, filled with ultra-high-purity nitrogen, and allowed to stand for 2 hours at room temperature (25°C). After 2 h, the gas was transferred to another bag, which was set on the differential odor analyzer for measurement.

Measurement of total protein content Total protein content was determined by the Folin-Lowry method. A standard curve was prepared using BSA solution. The absorbance of sample and protein standard was measured using a spectrophotometer at 500 nm (Lowry et al., 1951; Tangkhavanich et al., 2012).

Amino acid analysis The supernatant was filtered through a 0.2 μm filter and subjected to amino acid analysis (Hitachi L-8900 automatic amino acid analyzer). The amino acids were identified by comparison of their retention times with standards and were quantified using a calibration curve (Kulkarni et al., 2008b).

Measurement of total sugar content Sugar content was measured by the phenolic sulfuric acid method. Sample solution (1 mL) and 5% phenolic solution (1 mL) were both placed in a test tube, and 5 mL concentrated sulfuric acid was gradually added. The content of the test tube was immediately stirred, and then left at room temperature. Absorbance at 490 nm was measured using an absorbance meter.

Measurement of water-soluble pectin content A rapid and new specific colorimetric method for the determination of pectin content was established using carbazole-sulfuric acid. The procedure was as follows: a test tube containing 0.5 mL pectin solution was placed in an ice bath, 6 mL of a cold mixture of 1 part water and 7 parts concentrated sulfuric acid (special grade) were pipetted into the tube and mixed. Then, 0.2 mL of 0.1% alcoholic carbazole was added to the mixture in an ice bath. After shaking vigorously, the test tube was immersed in a water bath at 75°C for 20 min and cooled under running tap water. The absorbance of the colored solution was determined at 525 nm (Furutani et al., 1965).

Measurement of various catechins and caffeine content The levels of various catechins and caffeine in the extracts were measured by a previously developed method (Goto et al., 1996). The HPLC system consisted of a Waters e2695 pump with a two-pump gradient system, and a Waters 2998 UV detector. The column was a Develosil ODS-HG column (150 × 4.6 mm; Nomura Chem. Co., Seto, Japan) equipped with a guard column. The flow rate of the mobile phase was 1 mL/min. Detection was performed by measuring absorbance at 231 nm, and the column temperature was 40°C. The mobile phase compositions used were as follows: (A) water-acetonitrile-85% phosphoric acid (95.45:4.5:0.05, v/v/v); and (B) water-acetonitrile-85% phosphoric acid (49.95:50:0.05, v/v/v). The initial solvent composition was 90% solvent A and 10% solvent B; it was maintained for 5 min, then increased to 30% solvent B over 3 min. This condition was maintained for 2 min, followed by an increase of solvent B to 80% over 5 min. The final condition was held for an additional 5 min (Terada et al., 1987; Yoshida et al., 1999).

Results and Discussion
Catechin quantity with SWE and its characteristics The total catechin content of the green tea extracts was 317 mg/100 mL using hydrothermal extraction, 333 mg/100 mL using pressurized extraction, and 309 mg/100 mL using SWE. All values exceeded 300 mg/100 mL, and catechins were confirmed to have been extracted at a high concentration by all methods. We increased the reaction time slightly for heated water extraction, as this was shown to efficiently extract higher catechin yields from tea leaves (Ikeda et al., 1972). This extraction condition is used for industrial production and extracts catechins efficiently. In addition, pressurized extraction was employed to clearly illustrate the reaction differences with SWE. As SWE uses only normal water, it is safer and more reliable than solvent extraction, which uses alcohol for catechin extraction. In addition, the strong hydrolysis action of the sub-critical water results in decreased residual matter and, hence, it is an environmentally friendly method. Furthermore, the reaction time was shortened by about 1/10 compared to conventional heated water extraction, and it was possible to increase the extraction rate by 5 − 10%. The temperature and pressure used in this study are not very high, thereby minimizing the maintenance expenses of
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Therefore, the initial and last tastes of astringency were significantly reduced using SWE compared to hydrothermal or pressurized extraction. No differences in taste and acidity were observed according to the extraction method. Also, the results of organoleptic evaluation by human tasters correlated with the results of chemical analysis. Green tea that is less bitter and easier to drink can, through the consumption of large amounts of catechins, further promote the prevention and control of diabetes, arteriosclerotic heart disease, cancer and high blood pressure.

Evaluation of fragrance using differential odor analysis

Aroma, a component of taste, is an important element of green tea. The aroma of various green tea extracts was evaluated using a differential odor analyzer. Aroma characteristics of the samples are shown on a radar chart using nine reference gases. As a result, disagreeable odors, such as those of hydrogen sulfate, ammonia, sulfur compounds, and organic acids were found to be contained at high levels in the pressurized extract, but were lower in the hydrothermal and the device. The above results indicate the potential of SWE as a relatively inexpensive and innovative technique for the development of new food products.

Sensory evaluation

Sensory evaluation was carried out by 15 researchers from the green tea industry. Tasting was performed by adjusting the catechin content of each green tea extract to 180 mg/100 mL, which is about three times higher than the typical green tea catechin content (Kanbe et al., 2006). The sensory result was evaluated by the order method (Table 1). As a result, hydrothermal extraction produced a stronger taste than pressurized extraction and SWE. The green tea extract produced using SWE showed very weak bitterness. The pleasantness of the drink was in the rank order: SWE > hydrothermal extraction > pressurized extraction. In addition, the fragrance was judged to be good in the rank order: SWE > hydrothermal extraction > pressurized extraction. The green tea extract produced using SWE had the same catechin content; however, the bitterness was reduced and it was judged easy to drink. The SWE product will be judged by an instructor for Japanese green tea qualification and an expert in green tea evaluation in the future.

Evaluation of taste using taste sensor analysis

Since bitterness and astringency were suppressed by SWE, the extracts were analyzed using taste sensors to chemically validate the tasting results. The measurement results for the hydrothermal green tea extract were regarded as reference values (zero). Also, a difference of 1.0 on the radar chart corresponded to a Weber rate of 20% and is a concentration difference generally perceivable by humans. Compared with the hydrothermal method extract, the extract obtained by pressurized extraction showed sourness of 0, bitterness (initial taste) of -1.90 ± 0.15, umami of +0.56 ± 0.22, bitterness (last taste) of +0.40 ± 0.07, astringency (last taste) of +0.78 ± 0.09, and tastiness of +0.21 ± 0.23. The SWE extract showed sourness of 0, bitterness (initial taste) of -0.95 ± 0.35, astringency (initial taste) of +0.94 ± 0.45, umami of +0.22 ± 0.30, bitterness (last taste) of +0.19 ± 0.03, astringency (last taste) of -2.29 ± 0.20, and tastiness of +0.35 ± 0.12 (Fig. 1). Therefore, the initial and last tastes of astringency were significantly reduced using SWE compared to hydrothermal or pressurized extraction. No differences in taste and acidity were observed according to the extraction method. Also, the results of organoleptic evaluation by human tasters correlated with the results of chemical analysis. Green tea that is less bitter and easier to drink can, through the consumption of large amounts of catechins, further promote the prevention and control of diabetes, arteriosclerotic heart disease, cancer and high blood pressure.

Table 1. Sensory evaluation comparison of each extraction method

<table>
<thead>
<tr>
<th></th>
<th>Hydrothermal extraction</th>
<th>Pressurized extraction</th>
<th>Sub-critical water extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>90℃</td>
<td>120℃</td>
<td>130℃</td>
</tr>
<tr>
<td>Pressure</td>
<td>–</td>
<td>0.2 MPa</td>
<td>3.0 MPa</td>
</tr>
<tr>
<td>Extraction time</td>
<td>10 min</td>
<td>15 min</td>
<td>1 min</td>
</tr>
<tr>
<td>Bitterness/Astringency</td>
<td>Strong</td>
<td>Strong</td>
<td>Weak</td>
</tr>
<tr>
<td>Ease of drinking</td>
<td>Normal</td>
<td>Bad</td>
<td>Very good</td>
</tr>
<tr>
<td>Fragrance</td>
<td>Normal</td>
<td>Bad</td>
<td>Good</td>
</tr>
</tbody>
</table>

Results of organoleptic testing by human testers of green tea extracts obtained by conventional hydrothermal and pressurized extraction, and novel sub-critical water extraction. Organoleptic evaluation was performed by 15 tea researchers using a 5-point scale associated with various evaluation items (bitterness, astringency, drinkability, aroma). Results are expressed in rank order.

Evaluation of fragrance using differential odor analysis

Aroma, a component of taste, is an important element of green tea. The aroma of various green tea extracts was evaluated using a differential odor analyzer. Aroma characteristics of the samples are shown on a radar chart using nine reference gases. As a result, disagreeable odors, such as those of hydrogen sulfate, ammonia, sulfur compounds, and organic acids were found to be contained at high levels in the pressurized extract, but were lower in the hydrothermal and...
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dencies, and their aromas resembled each other. The odor of the pressurized extract differed from that of the hydrothermal or SWE extract and was judged to be disagreeable on organoleptic evaluation by tasting. Therefore, the components of the SWE green tea extract were similar to those of green tea brewed in a pot.

**Protein and amino acid contents**
We measured the protein and amino acid contents in the green tea extracts produced using each extraction method. As a result, the protein contents were: hydrothermal extraction, 96.5 mg/mL; pressurized extraction, 100.9 mg/mL; SWE, 87.1 mg/mL. Decreased protein content was confirmed in SWE. The results suggested that protein was hydrolyzed to free amino acids by sub-critical water. In addition, measurement results of the main amino acid related to green tea are shown in Table 2 (Anan et al., 1984). It was confirmed that serine, theanine, glycine, and arginine, which participate in the taste and sweetness of green tea, were increased in SWE, and serine and arginine were also significantly increased. Theanine and arginine are amino acids that participate greatly in the taste and sweetness of green tea, and characterize the taste of green tea. In addition, it was reported that arginine showed a mitigating effect on the unpleasant taste (Ogawa et al., 2004). Aspartic acid and theanine, alanine, tyrosine, and

![Fig. 2. Comparison of extraction methods in relation to the composition of fragrance ingredients using differential odor analysis.](image)

**Table 2. Comparison of amino acid, sugar, water-soluble pectin, catechin and caffeine content in the three extracts**

<table>
<thead>
<tr>
<th></th>
<th>Hydrothermal extraction (mg/100mL)</th>
<th>Pressurized extraction (mg/100mL)</th>
<th>Sub-critical water extraction (mg/100mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGCG</td>
<td>131.0 ± 3.7</td>
<td>120.6 ± 2.3</td>
<td>143.0 ± 6.5</td>
</tr>
<tr>
<td>ECG</td>
<td>19.2 ± 0.7</td>
<td>18.6 ± 1.3</td>
<td>8.8 ± 1.3</td>
</tr>
<tr>
<td>EGC</td>
<td>48.2 ± 0.9</td>
<td>34.0 ± 0.5</td>
<td>41.5 ± 1.0</td>
</tr>
<tr>
<td>EC</td>
<td>36.0 ± 0.2</td>
<td>29.8 ± 1.2</td>
<td>15.8 ± 0.4</td>
</tr>
<tr>
<td>GCG</td>
<td>31.1 ± 0.8</td>
<td>53.1 ± 2.1</td>
<td>18.9 ± 0.9</td>
</tr>
<tr>
<td>CG</td>
<td>2.4 ± 0.3</td>
<td>4.3 ± 0.7</td>
<td>3.4 ± 0.4</td>
</tr>
<tr>
<td>GC</td>
<td>37.6 ± 1.2</td>
<td>57.5 ± 1.2</td>
<td>62.5 ± 1.5</td>
</tr>
<tr>
<td>C</td>
<td>6.1 ± 0.9</td>
<td>9.7 ± 0.9</td>
<td>11.7 ± 1.8</td>
</tr>
<tr>
<td>Caffeine</td>
<td>37.8 ± 1.1</td>
<td>39.6 ± 1.3</td>
<td>36.4 ± 1.1</td>
</tr>
<tr>
<td>Serine</td>
<td>14.3 ± 0.2</td>
<td>15.1 ± 0.1</td>
<td>19.1 ± 0.1</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>28.8 ± 0.5</td>
<td>29.3 ± 0.3</td>
<td>24.7 ± 0.2</td>
</tr>
<tr>
<td>Glycine</td>
<td>0.5 ± 0.0</td>
<td>0.6 ± 0.0</td>
<td>0.8 ± 0.0</td>
</tr>
<tr>
<td>Arginine</td>
<td>15.4 ± 0.2</td>
<td>17.1 ± 0.1</td>
<td>22.1 ± 0.3</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>4.0 ± 0.1</td>
<td>4.0 ± 0.1</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>Theanine</td>
<td>46.3 ± 0.3</td>
<td>46.4 ± 0.4</td>
<td>48.0 ± 0.3</td>
</tr>
<tr>
<td>Alanine</td>
<td>11.7 ± 0.4</td>
<td>11.9 ± 0.6</td>
<td>10.6 ± 0.3</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>9.4 ± 0.3</td>
<td>9.3 ± 0.1</td>
<td>8.4 ± 0.1</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.8 ± 0.1</td>
<td>1.8 ± 0.1</td>
<td>1.3 ± 0.0</td>
</tr>
<tr>
<td>Total sugar</td>
<td>197.4 ± 4.9</td>
<td>201.9 ± 7.2</td>
<td>269.7 ± 7.2</td>
</tr>
<tr>
<td>Water-soluble pectin</td>
<td>6.1 ± 0.3</td>
<td>13.7 ± 0.8</td>
<td>23.5 ± 0.9</td>
</tr>
</tbody>
</table>

The content of catechin, caffeine, amino acid, total sugar and water-soluble pectin content in green tea extracts from the new SWE compared to conventional hydrothermal extraction and pressurized extraction.

Data are expressed as mean ± standard deviation (n = 5).
histidine were decreased with SWE. This indicates more active hydrolyzation of this extraction method than the conventional methods, and alteration of amino acid structure.

**Total sugar and water-soluble pectin content**  
We measured the total sugar and water-soluble pectin contents of the green tea extracts produced with each extraction method. The results are presented in Table 2. Saccharides, such as sugar or water-soluble pectin, reduced the strong unpleasant taste of the catechins, and a masking effect was proposed (Hayashi et al., 2005). Our results showed an increase in the quantity of all sugars and water-soluble pectin content in the SWE extract. After SWE, water-soluble pectin increased by about 4-fold compared to hydrothermal extraction, and about 2-fold compared to pressurized extraction. Although a previous study showed that polyphenolic astringency was controlled by pectin (Taira et al., 1997), the role of pectin in controlling green tea astringency required clarification. Therefore, pectin was added to four catechin-water solutions to evaluate the mitigating effect on astringency, assessed using taste sensor analysis. As a result, pectin clearly showed a lessening effect on EGCG and ECG (gallate-type catechins), as shown by Hayashi et al., (Hayashi et al., 2005), and also by the addition of pectin to brewed green tea. The results suggested that the saccharides interacted with the receptor responsible for the unpleasant taste detection, thereby masking bitterness and astringency. Taste sensor analysis was used to evaluate the EGCG-associated unpleasant taste following addition of water-soluble pectin. As a result, a decrease in astringency was confirmed with SWE of green tea; therefore, it was suggested that water-soluble pectin masked the strong unpleasant taste of catechins.

**Catechin and caffeine contents**  
We measured the catechin and caffeine contents of the green tea extracts produced by each extraction method. The results are shown in Table 2. As seen in the table, a tendency for each catechin to decrease was confirmed in SWE (Komatsu et al., 1993). This can be attributed to the degradation of catechins by the hydrolysis reaction in sub-critical water; however, the concentration of EGCG, a well-known functional compound, was found to be constant. Therefore, this indicates that the SWE green tea extract did not differ from extract produced by the conventional extraction method, and high functionality remained. Decreased ECG and EC were seen by other groups, and the possibility that decreased strength in ECG flavor was correlated to their sensory evaluation was proposed (Narukawa et al., 2010). The decrease in GCG suggested its hydrolysis by SWE, resulting in the separation of CG and gallic acid. In addition, no significant change was apparent in relation to caffeine content. As for the SWE green tea extract, while the quantity of extracted catechins did not change, it was understood that the composition of the catechins was altered (Chen et al., 2001). It is necessary to analyze differences in green tea functionality as a result of changes in catechin composition in comparison with the conventional extraction method. In addition, animal experiments should be employed in the search for new functional ingredients and effects, and to further examine the utility of SWE and its effective practical use.

**Conclusion**  
Our results suggested the following: 1) SWE successfully extracted catechins from green tea at high yields with less bitterness and astringency; 2) SWE was able to control the strong unpleasant taste peculiar to catechins; and 3) the cost and safety associated with a new SWE device will be acceptable because the reaction occurs at low temperatures and pressure.

Therefore, SWE offers many advantages as a food extraction technology for the effective development of new palatable green tea products. In order to mitigate the strong unpleasant taste peculiar to catechins, a masking effect using water-soluble pectin (polysaccharides) saccharide was proposed. Future studies will involve cellular analyses that include both the molecular responses of the receptor associated with the unpleasant taste and the elucidation of the inhibitory effects of saccharides on the receptor signaling mechanism.

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